AD-775 456

BLAST LOADING OF OBJECTS IN BASEMENT SHELTER MODELS

George A. Coulter

Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

January 1974

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BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 2348

JANUARY 1974

SUMMARY

BLAST LOADING OF OBJECTS IN BASEMENT SHELTER MODELS

George A. Coulter
Terminal Ballistics Laboratory

This work was supported by Defense Civil Preparedness Agency,
Work Order No. DAHC 20-70-C-0310, A#2 Work Unit 1123C

ABERDEEN PROVING GROUND, MARYLAND

I. INTRODUCTION

This report is a part of a study for the Defense Civil Preparedness Agency under Work Order No. DAHC 20-70-C-0310, A#2; Work Unit 1123C, "Blast Loading in Existing Structures". Results are presented for the blast induced loading on objects inside 1/12th scale model basement shelters. The work assumes that the external blast wave will destroy and blow away the above ground structure. The blast wave is assumed then to enter the basement shelter through open stairways, elevator shafts and other openings that are left.

The work reported here is a continuation of that reported in BRL Memorandum Report 2208 (Ref. 1). The BRL 24 inch shock tube was modified, since that work, by the addition of a longer driver section which increased the duration of the input shock wave for the smaller model experiments. Also, an additional model was built for use with the BRL 5.5 foot shock tube, to simulate a 1000 shelteree size basement shelter. Results are also presented for this larger model.

II. EXPERIMENTS

The first experiment made use of the same basement model (40 x 70 x 8 inches) as used for the experiments reported in Ref. 1. A larger driver section (35 1/2 ft) was added to the shock tube. The added driver length increased the positive, flat duration of the input shock-waves. As in the earlier experiments, pressure transducers and high speed framing cameras were used to record the pressures and object translation within the basement model.

A second basement model was built to simulate a 1000 shelteree shelter. This larger model (70 x 144 x 8 inches) was constructed to be used with the BRL 5.5 ft. shock tube to take advantage of still greater shock wave duration. Input pressure of 5 and 10 psi were used to create the internal flows within the basement models which in turn, caused the objects to translate. Pressure-time records of input shock waveforms and pressure fill records were taken and high speed 16 mm cameras (2000-3000 pps) recorded the motion of nylon cylinders placed within the models prior to shock wave exposure.

III. RESULTS AND CONCLUSIONS

A summary of the shots is given in the appendixes of this report along with pertinent data for the shots. Velocity field predictions for the interior air flow induced by an input shockwave are given by the RIPPLE code.

Some pertinent results are summarized for the two sets of experiments.

A. Model 40 - Single Closed Stairway

1. Nylon cylinders caught in the incoming jet-like flow from the stair entrance were translated away from the entrance and toward the left rear area of the model. The translation speed of the cylinders varied from a few ft/sec for the 5 psi input to about 36 ft/sec for the input of 20 psi.

2. Cylinders positioned outside the jet-flow limits were caught at later times into the long-term rotation of the internal flow. These observed speeds of cylinder translation were less than 5 ft/sec.

3. The cylinders, when caught in the high speed jet-flow, rotated, if airborne, as they were translated. For example, rotations of 36 rotations/sec were measured for the 20 psi shock wave input.

B. Model 42 - Stairway and Elevator Shaft

1. Cylinders placed in the center of the incoming flow from the stairway were translated to speeds of 17 and 38 ft/sec corresponding to input pressures of 5 and 10 psi.

2. Cylinders near center of room showed only slight motion.

3. The general pattern of motion for all cylinders was similar to that of Model 40, clockwise around the model from the entrances.

4. Generally translational speeds of the cylinder were higher, proportional to the six-time V/A increase for Model 42 over Model 40.

C. Predictions for Full Size Shelters

Fill-time predictions of cylinder motion for a variety of basement shelter are shown as a function of their volume to entrance area ratio. The flow parameters from these predictions are used to predict maximum translational speeds for cylinders calculated for each of the different basement sizes. In all cases, the cylinders were assumed to remain in the center and in a maximum flow region. Friction from the floor and the effect of gravity are neglected.

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13. ABSTRACT

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Details of illustrations in this document may be better studied on microfiche.

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B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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GACoulter/njs
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LIST OF SYMBOLS

a	Acceleration, ft/sec^2
A	Area of entrance to model, ft^2
A_c	Frontal area of cylinder, $in.^2$
A_1	Ambient sound speed of air, ft/sec
A_2	Sound speed behind shock, ft/sec
C_D	Coefficient of drag, Force/(Q_{stag} A_c), non-dimensional
H	Height of basement model, ft
L	Length of model, ft
m	Mass of cylinder, slugs
M_2	Flow Mach number behind shock, non-dimensional
P_{center}	Pressure at the center of basement model floor, psi
P_1	Ambient air pressure, psi
P_s	Overpressure behind shock, psi
P_{stag}	Stagnation overpressure, psi
Q	Dynamic pressure, $1/2\ \rho u^2$, lb/ft^2
Q_{stag}	$P_{stag} - P_s$, psi
R_e	Reynolds number, non-dimensional
t	Time, sec
T_1	Ambient air temperature, deg F
T_2	Temperature behind shock, deg F
T_{fill}	Time to fill model to input pressure in the shock tube, sec
Time Zero	Defined to be when shock wave exits stairway
u_1	Ambient air speed, ft/sec
u_2	Speed of air flow behind shock, ft/sec
V	Internal volume of basement model, ft^3
V/A	Internal volume to entrance area ratio of model, ft
W	Width of model entrance, ft
X	Coordinate in direction of model width, in.
Y	Coordinate in direction of model length, in.
ρ_1	Ambient air density, $slug/ft^3$
ρ_2	Density behind the shock, $slug/ft^3$

I. INTRODUCTION

The work being reported is a part of a study for the Defense Civil Preparedness Agency under Work Order No. DAHC 20-70-C-0310, A#2; Work Unit 1123C, "Blast Loading in Existing Structures". Results are presented for the loading experienced by objects in a model basement shelter when exposed to shock waves entering the room. The work assumes that an external blast wave will destroy and remove that portion of the structure above ground. The blast wave is then assumed to enter the basement through the open stairways, elevator shafts, and remaining openings.

The work reported here is a continuation of that reported in BRL Memorandum Report 2208 (Ref. 1). A longer driven section has since been added to the BRL 24-inch shock tube which has increased the duration of the input shock wave. This has allowed the smaller model to be exposed to another set of input conditions for longer fill times. A larger basement model representing a 1000 shelteree shelter was built for use on the BRL 5.5-foot shock tube. Results are presented for this model and compared to those obtained for the smaller (80 shelteree) basement model exposed at the 24-inch shock tube.

II. EXPERIMENTS

The experiments are reported in two parts, Part A which concerns the work done with a basement model exposed to shock waves from the 24-inch shock tube, and Part B which reports the experiments with a larger model at the 5.5-foot shock tube.

A. Basement Model 40-24 inch Shock Tube

Model 40 measured 20 x 40 x 8 inches in size and simulated a 1/12th scale basement shelter capable of holding about 80 shelterees at 10 feet^2/person. The model was designed with a single closed stairway with an opening of 4.75 x 8 inches. The model volume to entrance area ratio, V/A, was approximately 14 feet.

The instrumentation included Susquehanna Instrument ST-2 pressure transducers coupled with Kistler Model 566 charge amplifiers to Textronix 502-A oscilloscopes. These were used to measure the input shock overpressure and also the model's interior fill pressure. Fastex 16 mm framing cameras running at 2000-3000 pps were used to record the motion of nylon cylinders (1.28" dia x 1.83" high, weight 1.56 oz.) exposed to the shock-created internal flows. Figures 1 and 2 show the model attached to the 24-inch shock tube and a schematic of the floor grid where the cylinders were placed.

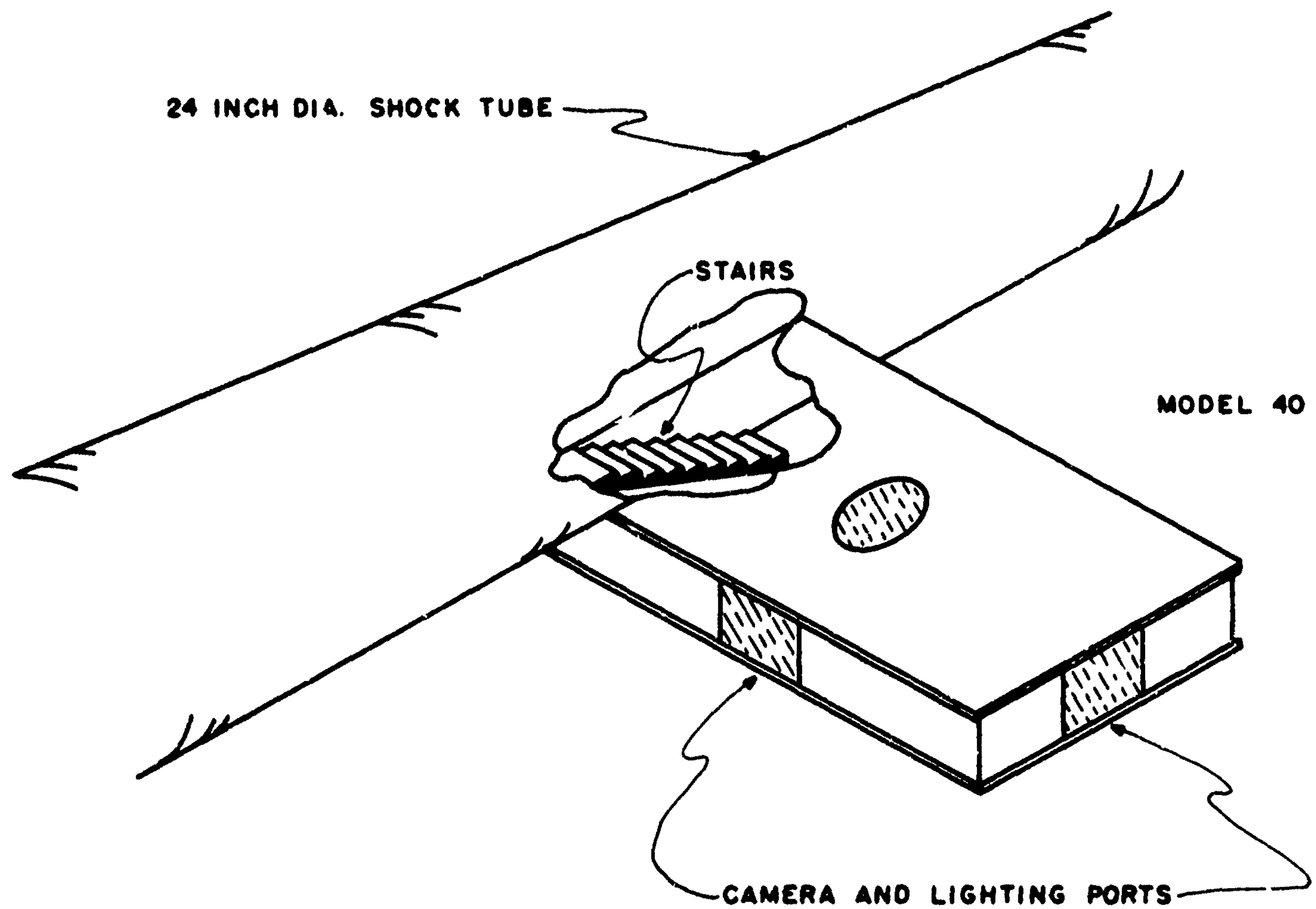


Figure 1. 1/12th Scale Basement Model-24 inch Shock Tube

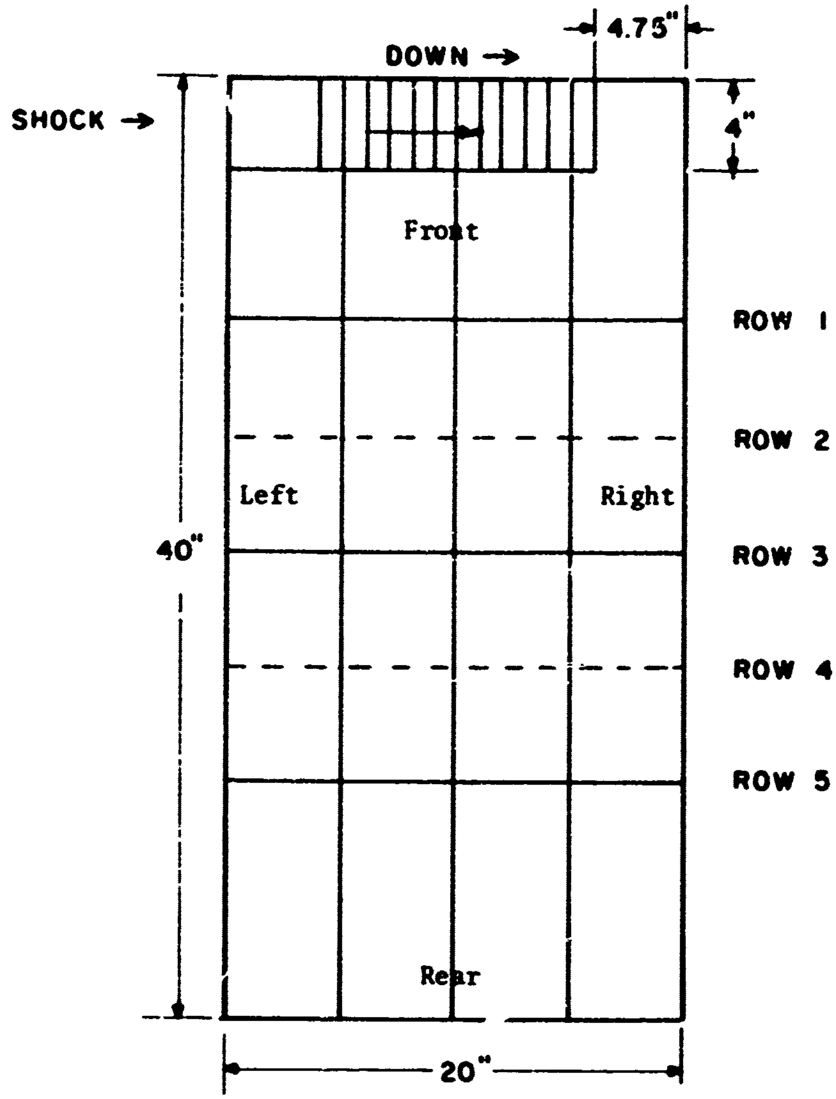


Figure 2. Floor Plan for Cylinder Experiments

The experimental procedure was to place a row of three cylinders across the floor of the model and allow a shock wave to enter the model. A series of 5, 10 and 20 psi input waves was used for the cylinders placed at the different rows shown. During the shot time, the motion of the cylinders was recorded by cameras placed at the end and the side. Photographs of the cylinders' motion and tables of average translational velocities are given in the Results Section, Part A.

B. Basement Model 42-5.5 Foot Shock Tube

A larger basement model, also 1/12th scale, with a size of 70 x 144 x 8 inches was built and attached to the 5.5 foot shock tube. An elevator-stairway entrance combination was built at the shock tube end for entrances into the model. Figures 3-5 describe the model. The size was chosen to approximate a full size shelter with space for 1000 shelterees at 10 ft^2/person. The shelter volume to total entrance area ratio was about 85 feet.

The instrumentation was similar to that used earlier except that longer time response was needed for the several hundred milliseconds duration shock waves. Accordingly, strain gage type transducers manufactured by Bytrex (Series HFG) and CEC (Type 4-312) were used instead of the ST-2 transducer. Also, a multichannel oscillograph recorder was used with CEC System D amplifiers for the strain transducers outputs.

The camera system was enlarged by one camera and mostly were used at the side position. Additional DXC 500 watt photoflood lamps were needed for a total of fourteen lamps. The framing rate was again held between 2000 and 3000 pps.

A pressure range of 5 and 10 psi input shock waves was used and the motion of the nylon cylinders observed. Since the basement model was large, twenty cylinders were used inside of three as before. The results of these experiments are given in the Results Section, Part B.

III. RESULTS

The results are presented in two parts. Part A describes the results obtained from Model 40 and Part B the results from Model 42.

A. Model 40-80 Shelteree Size

A summary of the shots to which model 40 was exposed is given in Appendix A, Table A-I. A representative set of pressure-time records obtained from the input transducer located 41 inches upstream of model entrance and the interior transducer, located flush in the center of floor, are shown in Fig. 6. The input shockwave has an approximately

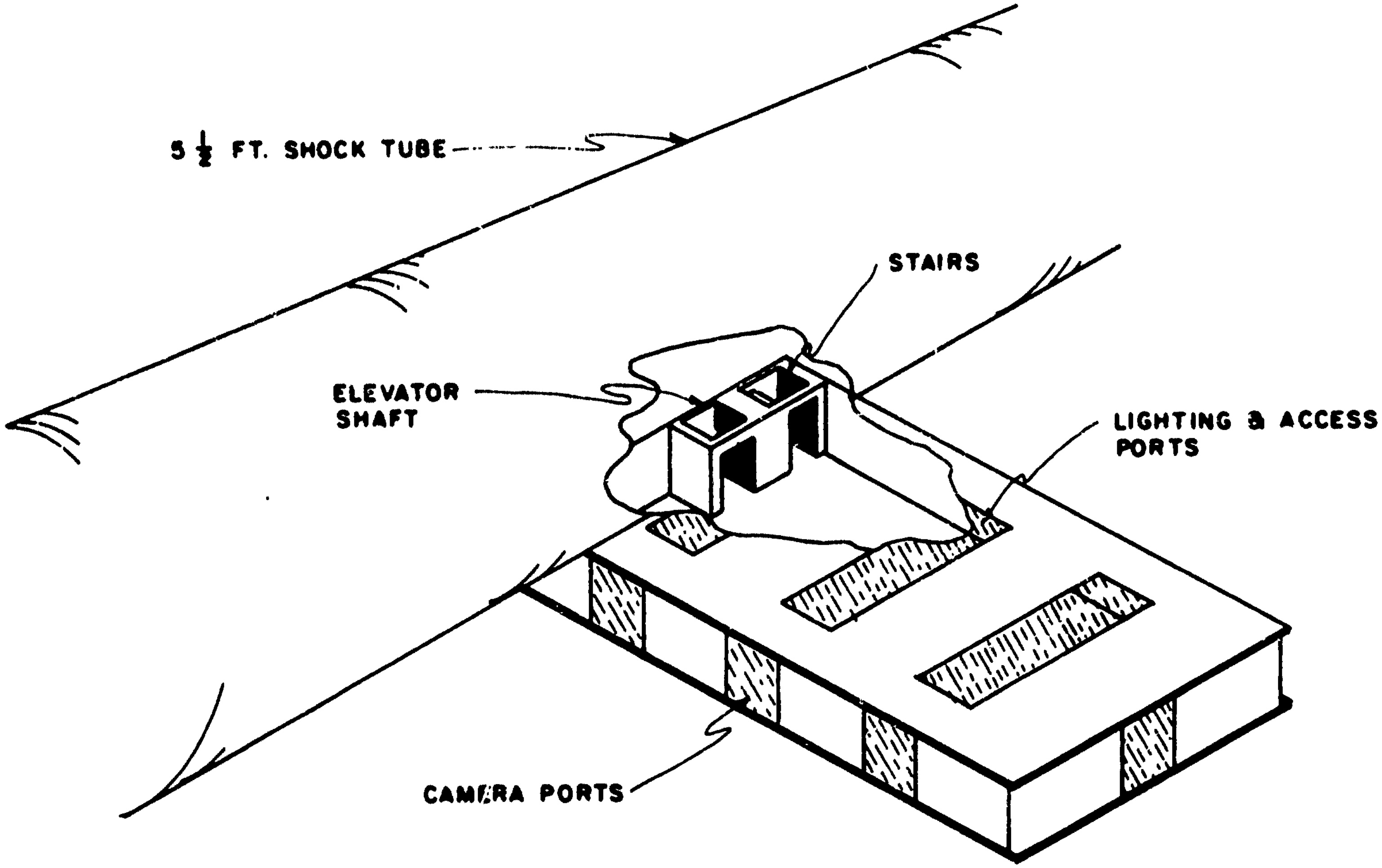
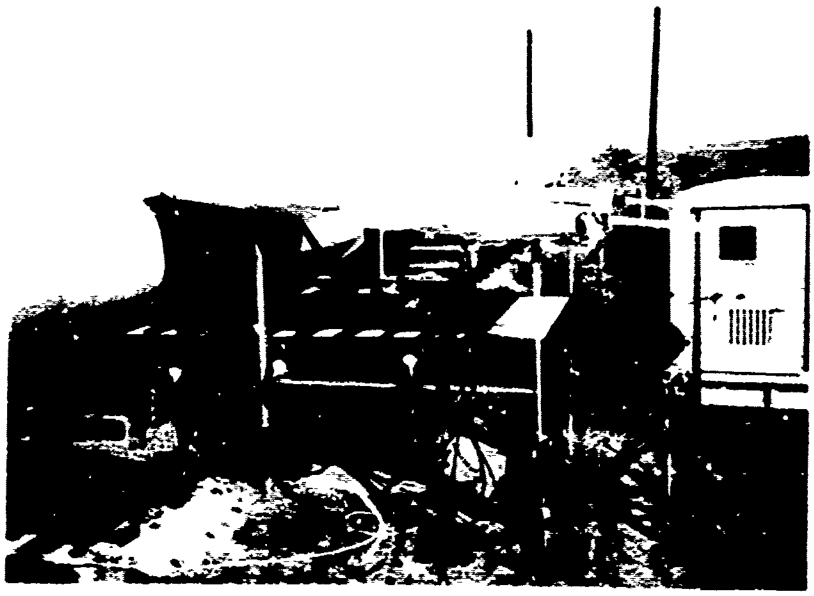
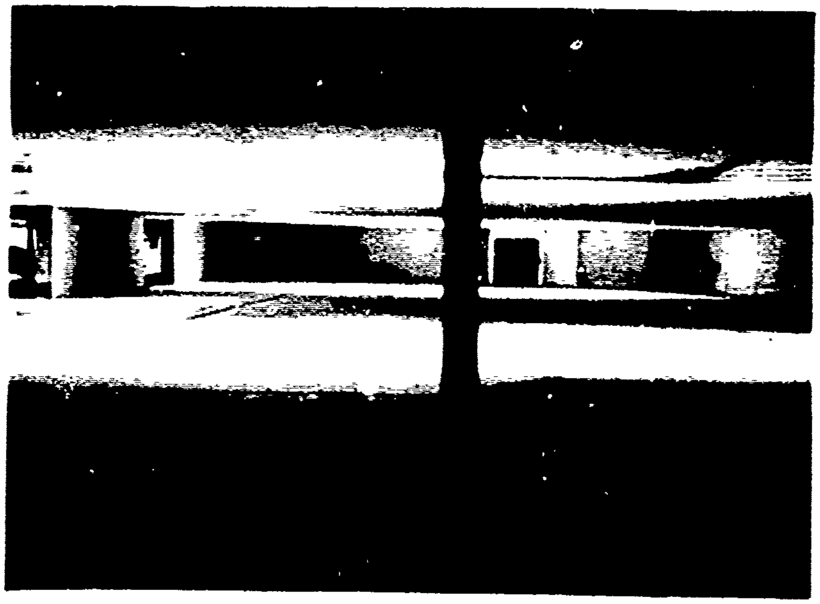


Figure 3. Model 42-1000 Person Basement Shelter Model



(A) MODEL 42 INSTALLED ON 5.5 FT. SHOCK TUBE



(B) INTERIOR VIEW OF MODEL 42

Figure 4. Photographs of Model 42

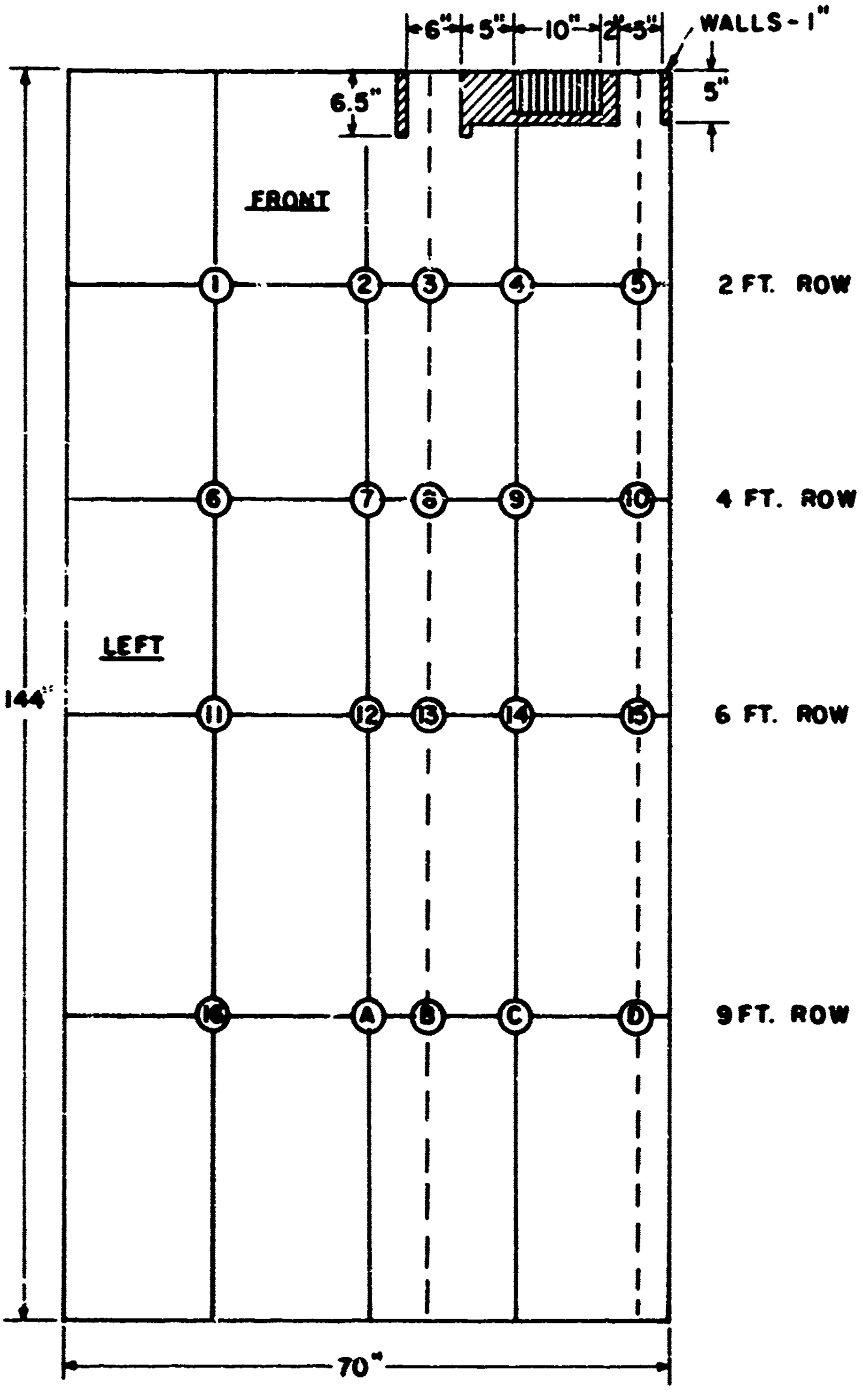


Figure 5. Location of Nylon Cylinders-Model 42

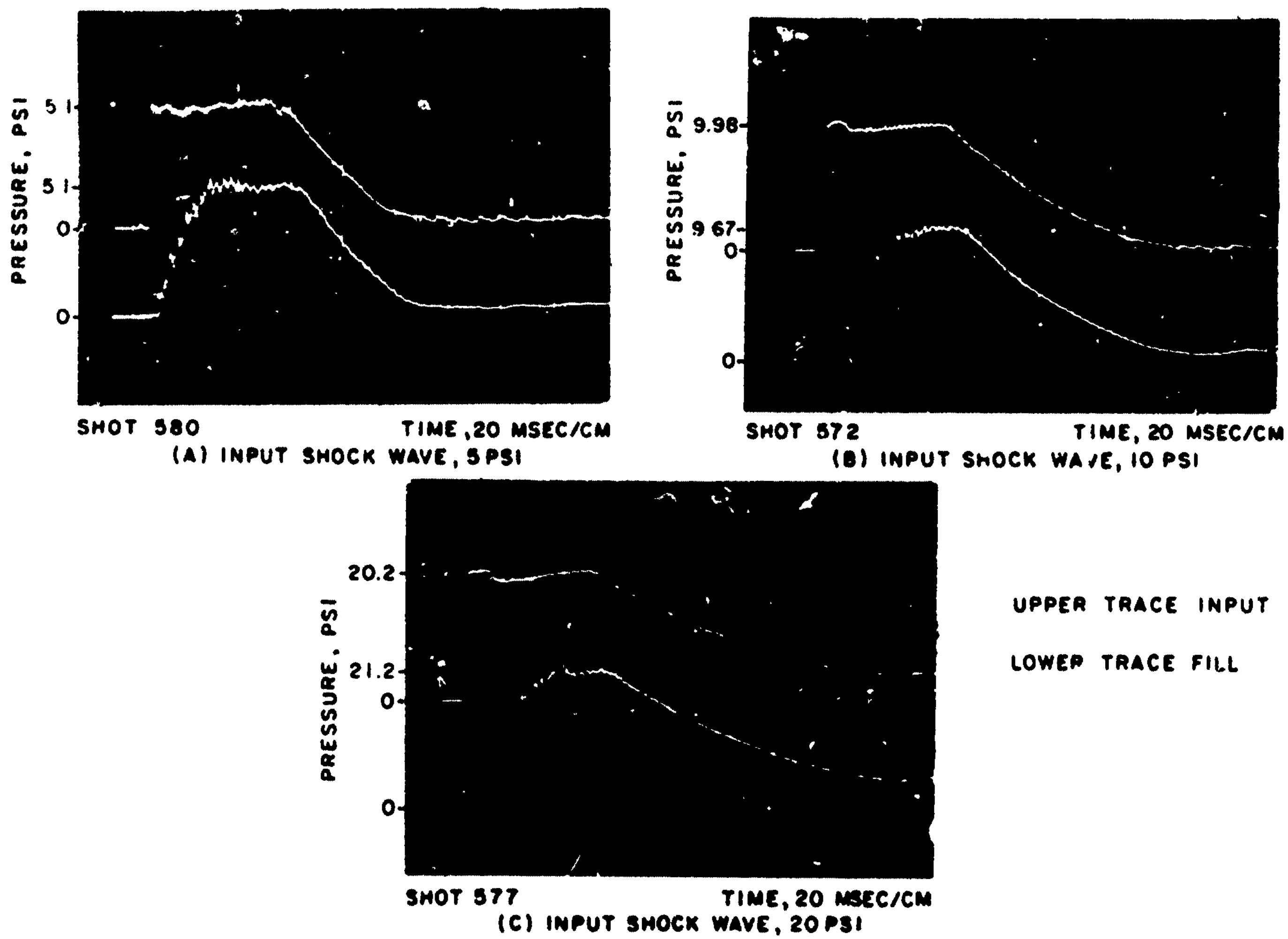


Figure 6. Typical Pressure-Time Records-Model 40

flat portion of about 45 msec. long. The slight dip at about 10 msec is caused by the filling rarifaction wave moving upstream from the model.

At all three input pressure levels the model was completely filled with pressure to the value of the outside shock pressure. Predictions have been made in Ref. 2, 3 and 4 that incoming air flow from the entrance is jet-like and attains a speed of several hundred feet/sec near the entrance. Other areas may maintain the order of 50-100 ft/sec for times several times the amount of the filling time. These predictions are compared with the experimental results later, in Section IV.

The purpose of the high speed photography was to record the effect of these interior flows upon the cylinders placed in various locations inside the model. Figures 7 and 8 show some of this motion as recorded by the Fastex cameras at the end and side of Model 40. Additional pictures are given in Appendix B. The motion is summarized in Table I as a function of cylinder location and input shock overpressure. In all shots the cylinders were arranged from left to right "A", "B", and "C". This placed "C" near the entrance, exposed to the highest air flow speeds.

B. Model 42-1000 Shelteree Size

The shot series for Model 42 is given in Appendix A, Table A-II. Typical records for the input shock waves for the shot series and the related filling pressure records are shown in Fig. 9. The input shock wave is seen to have a flat portion of 180-190 milliseconds duration. This is more than enough time for the filling curve to reach the input shockwave pressure at 100-150 milliseconds.

Photographs of the motion of the cylinders as they are affected by the shock created internal air flow are shown in Fig. 10-12. As in the smaller Model 40, the cylinders placed in the incoming high speed flow from the stairway were translated at speeds of 17 and 38 ft/sec for inputs of 5 and 10 psi. Other cylinders out of the main flow and near the center of the floor, moved only a slight amount. Generally, the observed pattern of motion for the cylinders was quite similar to that of Model 40. The main difference of greater maximum translational speeds for the cylinders can be attributed to the increased filling time for Model 42 as indicated by a V/A of about six times that of Model 40. Table II summarizes the data from Model 42.

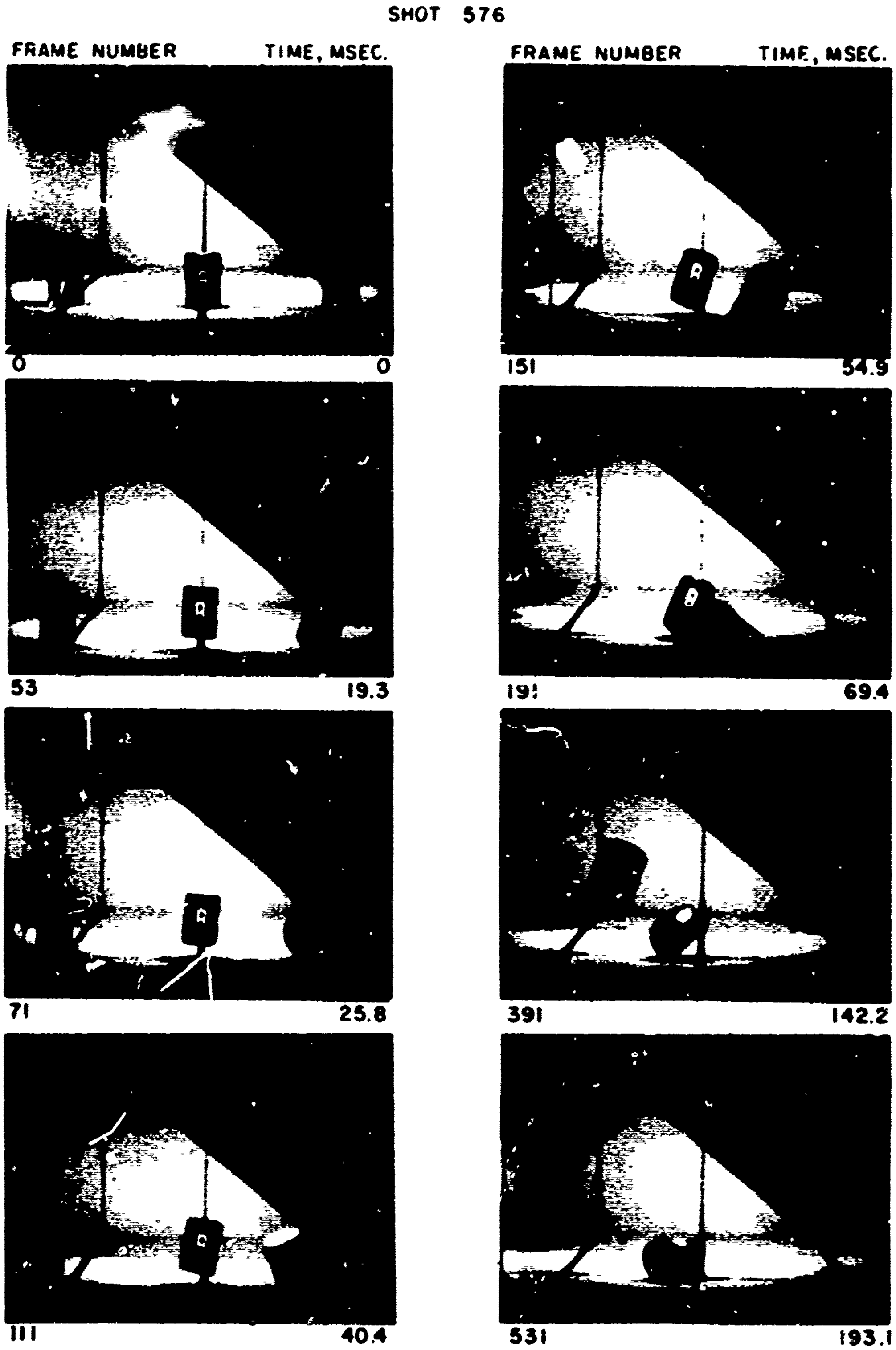


Figure 7. End View, Cylinders on Row 3-Ps = 20.1 psi

SHOT 576

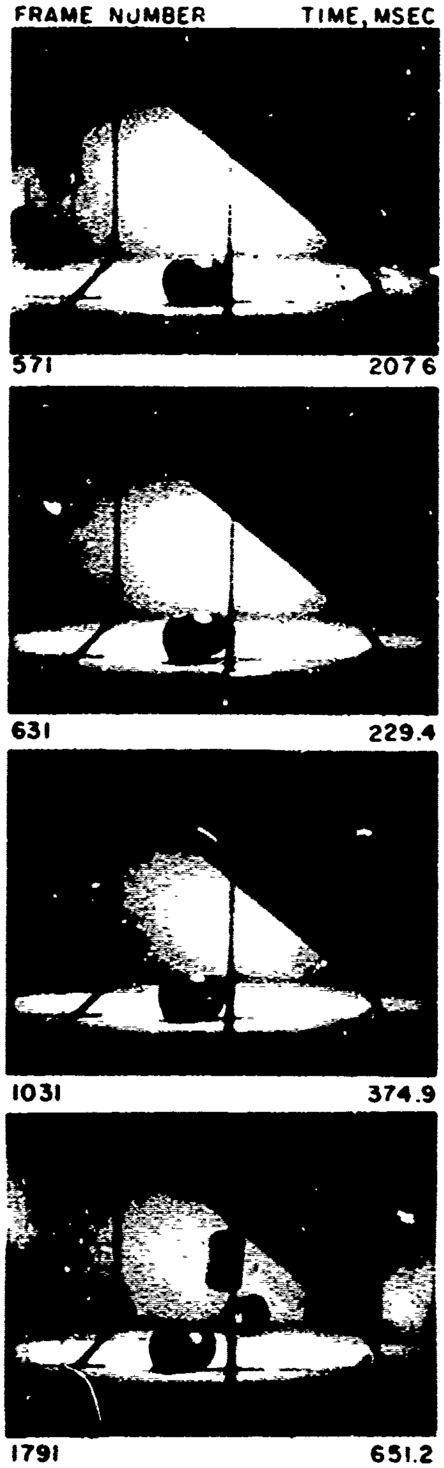


Figure 7. Continued

SHOT 576

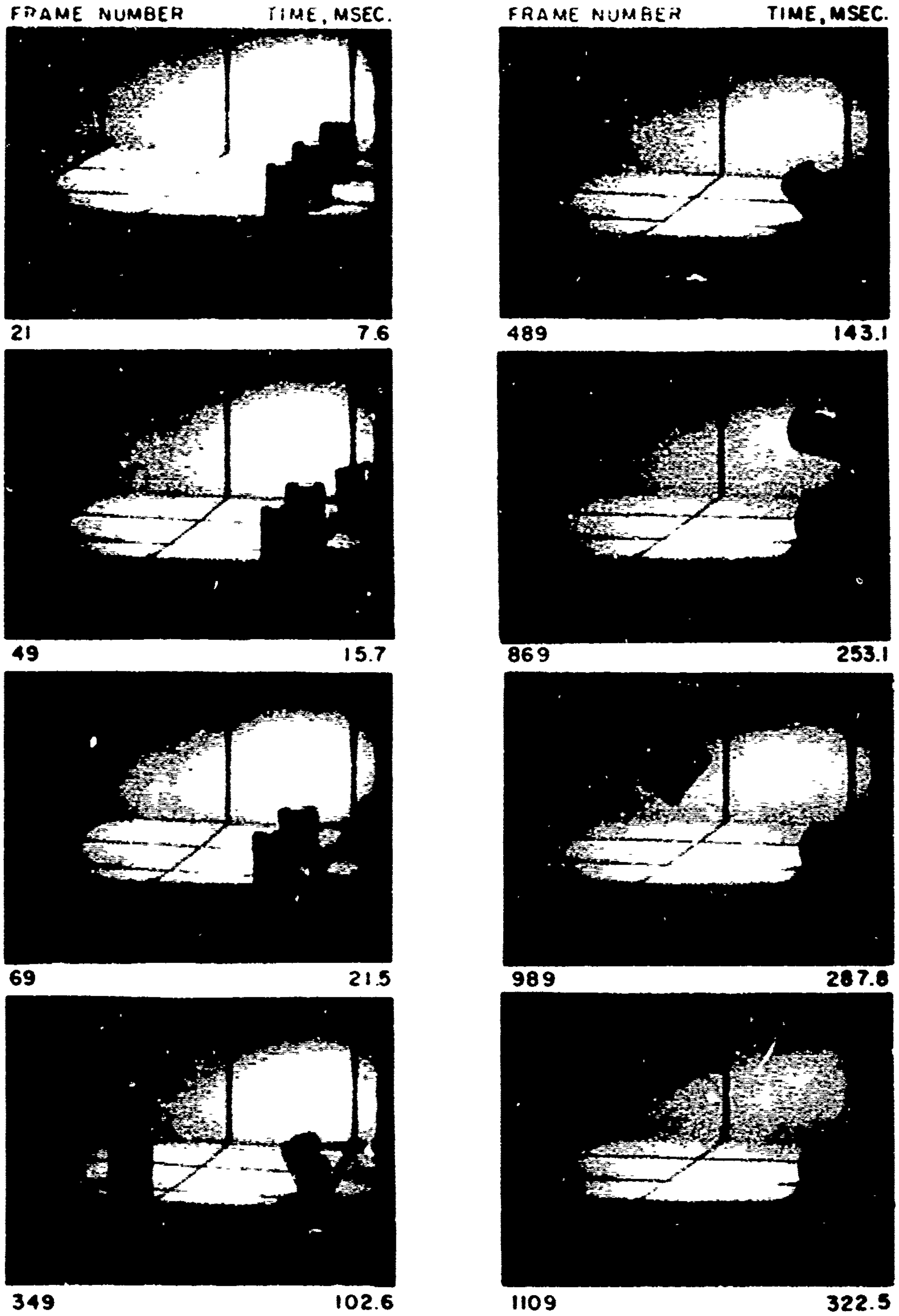


Figure 8. Side View, Cylinders on Row 3-Ps = 20.1 psi

Table I. Summary of Motion of Cylinders-Model 40

Cylinder	Input Pressure,psi	Motion of Cylinders			
		Row 1	Row 2	Row 3	Row 5
A	5	Slightly toward stairs	Slight	Slid toward stairs	slid slightly
	10	Slight	Did not fall	2-4 ft/sec toward stairs	4 ft/sec toward stairs
	20	Slid to left toward stairs	< 2 ft/sec	Airborne,6 ft/sec to left of stairs	Did not fall
B	5	Slightly toward stairs	Slight	Slight	Slight
	10	Fell down	Tilted	2-4 ft/sec toward stairs	Slid toward stairs
	20	4-9 ft/sec away from stairs	< 2 ft/sec	Fell over	Tumbles at 8-10 rot/sec
C	5	3-4 ft/sec away from stairs	1-2 ft/sec	1 ft/sec	Slid only
	10	11-15 ft/sec away from stairs	5 ft/sec away from stairs	2-4 ft/sec away from stairs	Slid slightly toward stairs
	20	36 ft/sec to diagonal left rear away from stairs	11-30 ft/sec to left rear	8-13 ft/sec to left rear	9 ft/sec toward front to stairs

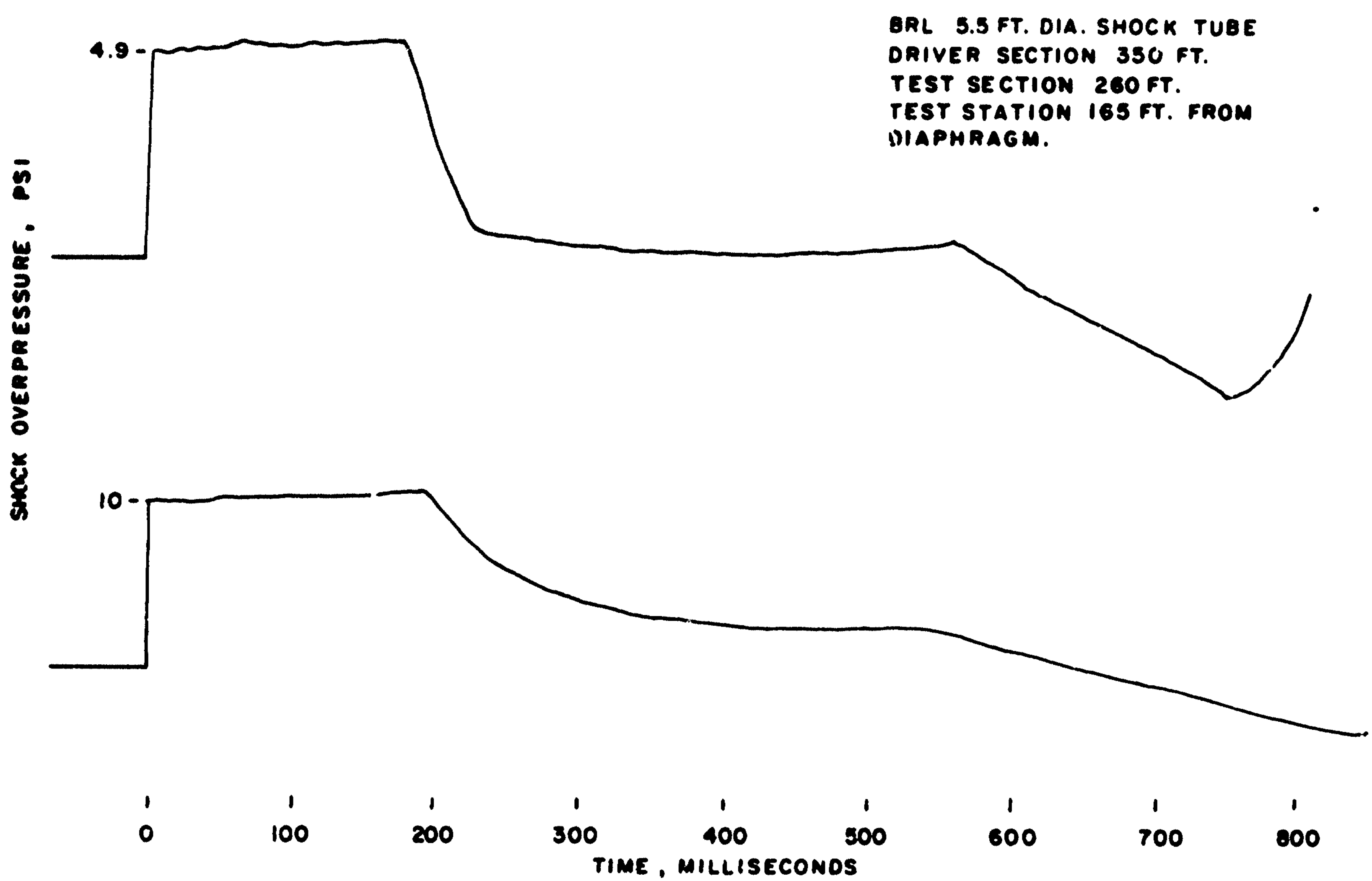


Figure 9. Typical Pressure-Time Curves for Model 42

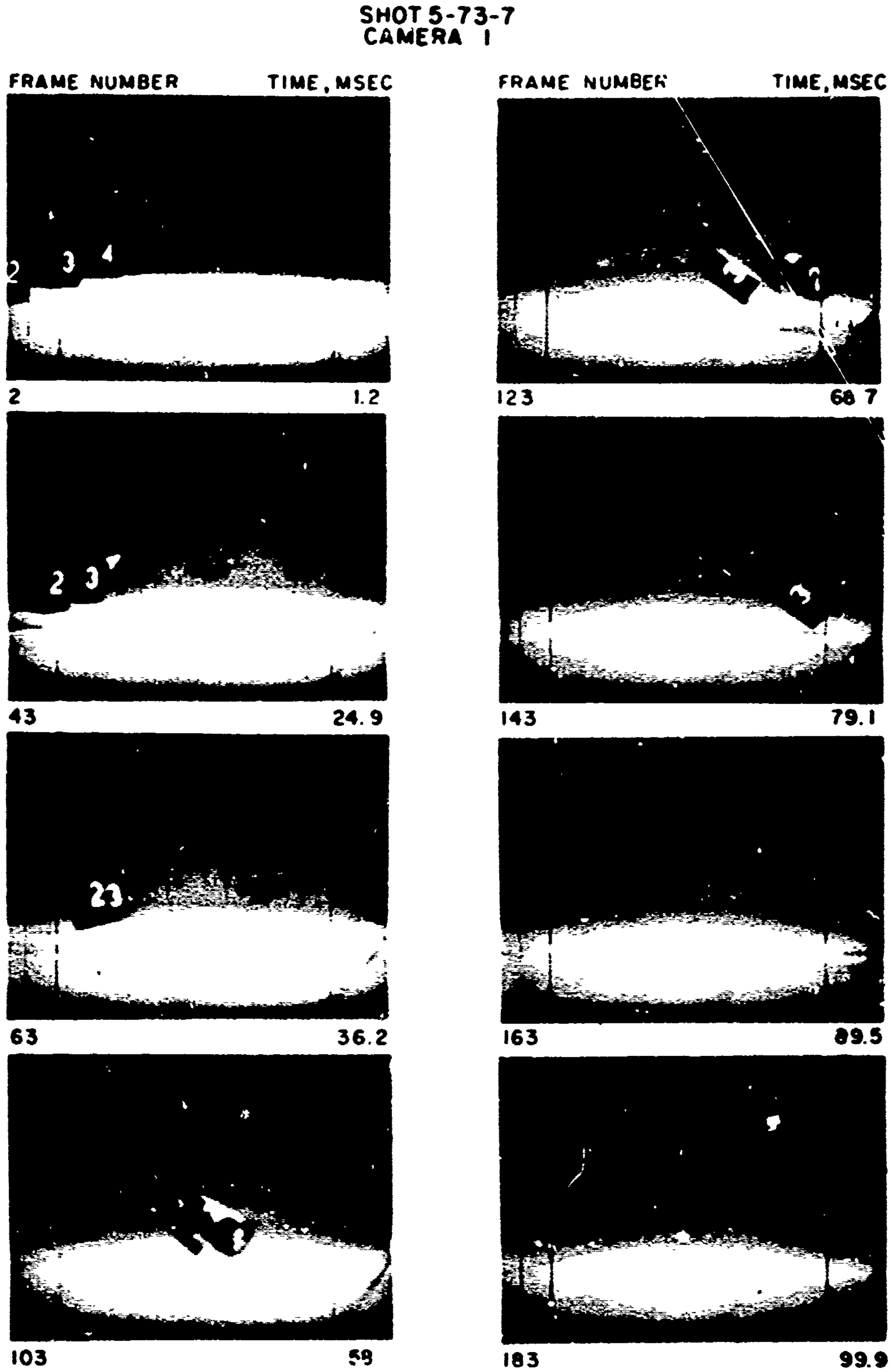


Figure 10. Camera 1, 2-ft Row, Model 42

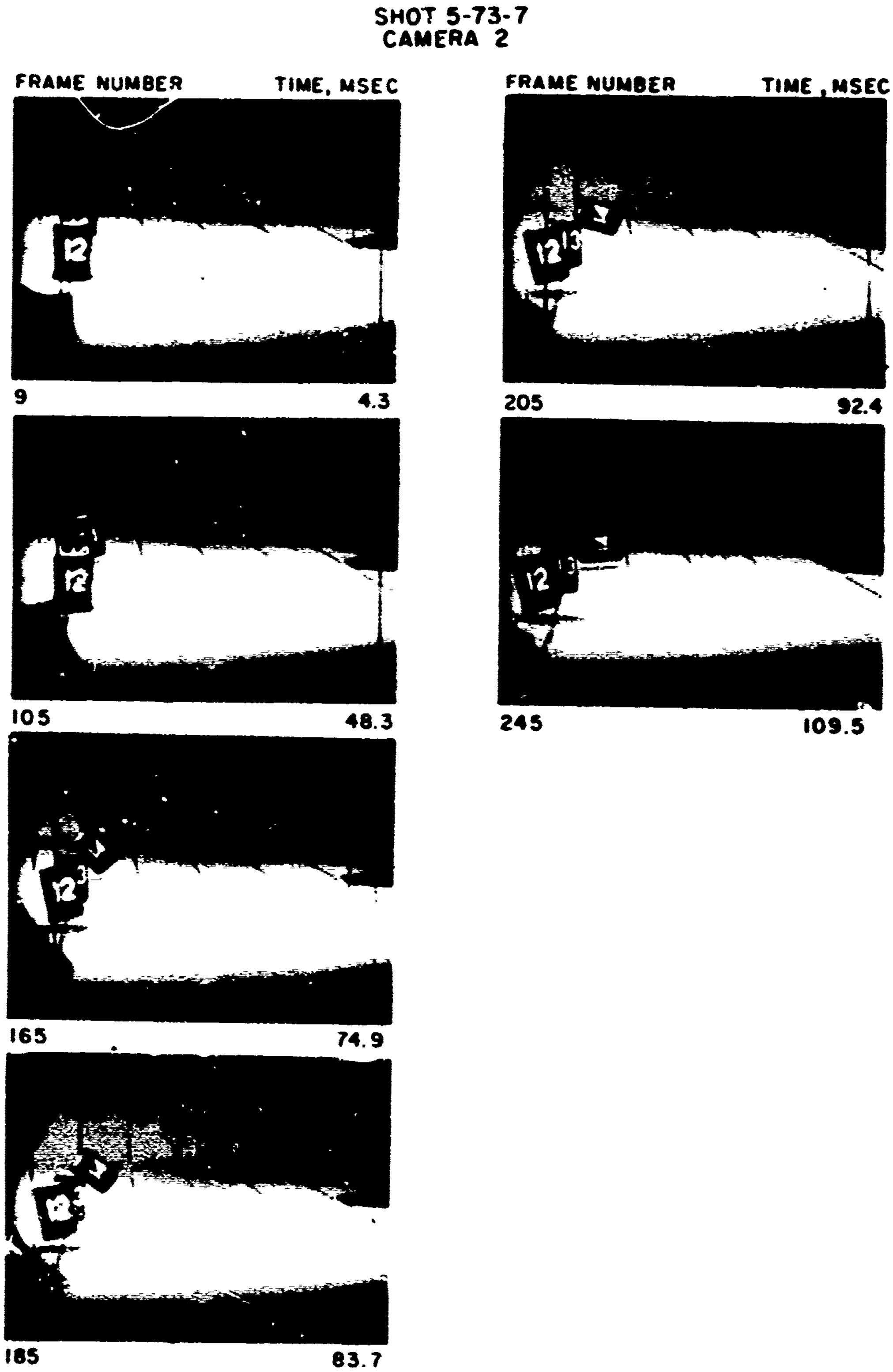


Figure 11. Camera 2, 6-ft Row, Model 42

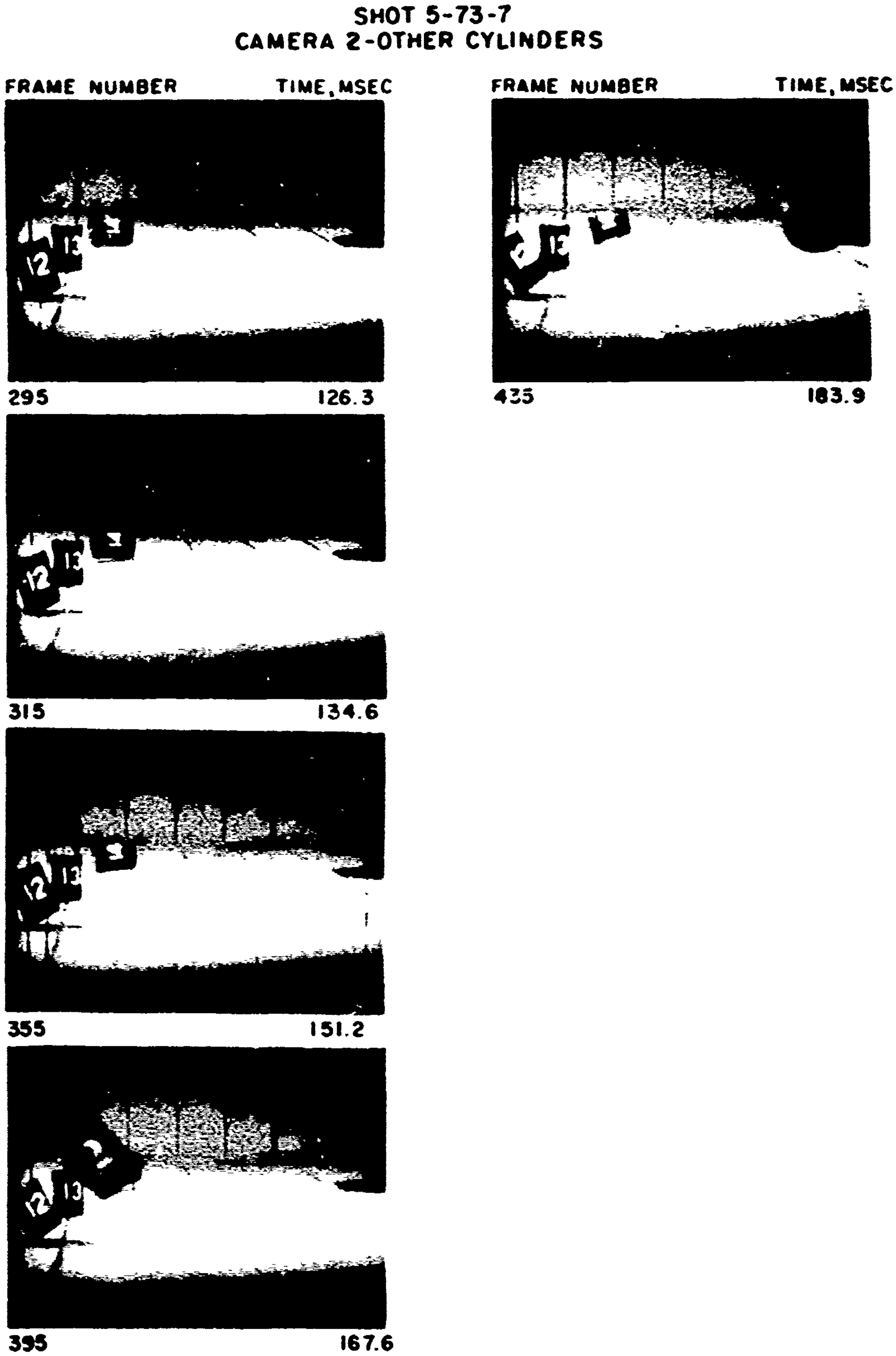


Figure 12. Camera 2 - Cylinders from Other Rows

Table II. Summary of Motion of Cylinders-Model 42

Input Pressure 5 psi

Camera 1, 2ft-3ft lines		Camera 2, 6ft-7ft lines		Camera 3, 9ft-10ft lines	
Cylinder Numbers	Motion of Cylinders	Cylinder Numbers	Motion of Cylinders	Cylinder Numbers	Motion of Cylinders
1	Not seen	6,7,8,9	Not seen	All Cylinders seen.	Little Motion
2&3	14-17 ft/sec	11	Not seen		
4	2-3 ft/sec	12,13,14	Slight motion		
5	17 ft/sec,max	15	7 ft/sec		
		10	7 ft/sec		
		5	8-10 ft/sec		
		3	4-6 ft/sec		
		Input Pressure 10 psi			
1	Not seen	6,7,8,9	Not seen	A	Not seen
2	15 ft/sec	11,12,13	Slight motion to front		
3	8-12 ft/sec			B&C	Little Motion
4	Little motion	14	2-3 ft/sec	D	10-12 ft/sec
5	24 ft/sec,max	15	19 ft/sec,max	15	23-30 ft/sec
		10	20-26 ft/sec	10	23-34 ft/sec
		5	23-33 ft/sec	5	21-38 ft/sec
		4	Slight	3	10 ft/sec
		3	10-13 ft/sec	Other Cylinders Not Seen.	
		2	32-58 ft/sec		
		1	Not seen		
		16	3.5 ft/sec to front		

IV. COMPUTER CODE PREDICTIONS

Three types of predictions were made with the help of computer codes. (1) Prediction of interior filling of the models with pressure, as a function of time, were made with the BRL Filling Code, Ref.1. (2) Two-dimensional hydrodynamic code predictions of the interior flows were made for Models 40 and 42, for an input of 10 psi, with the RIPPLE Code, Ref. 2. (3) Translation calculations were made for cylinders by making use of the flow parameters obtained from Filling Code predictions.

A. Fill-Time Predictions

Interior pressure filling predictions for Model 40 are shown as Table III for 5, 10 and 20 psi input shock pressures. The pressure filling from the table are plotted as a function of time in Fig. 13-15. They are plotted as solid lines, the input pressures as dotted lines and some "X's" for experimental points. There is some scatter in the data caused by peak reflections of the internal shock waves. Also, the stairs have been neglected as a correction to the total room volume and was neglected as a source of possible choking of the entrance flow. Similar predictions for Model 42 are given in Table IV and Fig. 16 and 17.

B. RIPPLE Code Flow Predictions

RIPPLE Code predictions of shock induced internal flow for a 10 psi input were made for Models 40 and 42. An example for Model 40 is shown in Fig. 18 for a time of about 5 msec. The time was chosen to start when the input shock wave entered the room from the entryway. The vector scale is shown at the bottom of the figure. A wide range of flow speeds exist at this time. Flows vary from a maximum of 650-750 ft/sec at the entryway corner, to 200ft/sec near center of room, to 50-100 feet near vortex, and to less than 20 ft/sec in the corners of the room. Although the RIPPLE Code is two-dimensional, it does seem to describe sufficiently well the actual three-dimensional room. A set of figures for Model 40 (two dimension) are given in Appendix D for flows at other times of interest.

A similar example of a flow field for Model 42 is shown in Fig. 19. The two entrances are seen to modify the flow field somewhat. The vortex location is displaced but the overall flow pattern for Model 42 resembles that of Model 40. The predicted ranges of flow speeds for the 10 psi input pressure are from 600-800 ft/sec near the entrance, 100-150 ft/sec across center of room, and 100 ft/sec near vortex. The set of flow charts are found in Appendix E.

C. Translation Calculations for Cylinders

Predictions of translation, velocity and acceleration for a nylon cylinder placed directly in the path of the incoming high speed flow were made for each of the two basement models. The simplified calculations for the parameters as a function of time, measured from diffracted shock arrival at the cylinders position, were made with a programable desk calculator.

Table III. Fill Parameters for Model 40

Model 40
Shot 569 5psi

AREA1	VOLUME	TIME	PRESSURE	DENSITY
0.264E 00	0.370400E 01	0.200000E-02	0.145000E 02	0.293700E-02

TIME SECONDS	PRESSURE PSI	DEN3 UE-S2/F4	U2 FPS	OPT PSI
0.200E-02	0.110568E 01	0.249548E-02	0.490901E 03	0.197868E 01
0.400E-02	0.208339E 01	0.264195E-02	0.412297E 03	0.147097E 01
0.600E-02	0.294322E 01	0.277066E-02	0.346933E 03	0.108774E 01
0.800E-02	0.367233E 01	0.287980E-02	0.283722E 03	0.754226E 00
0.100E-01	0.423518E 01	0.296420E-02	0.213094E 03	0.438089E 00
0.120E-01	0.461982E 01	0.302198E-02	0.142729E 03	0.200864E 00
0.140E-01	0.484458E 01	0.305574E-02	0.822119E 02	0.676167E-01
0.160E-01	0.495154E 01	0.307179E-02	0.387624E 02	0.151576E-01
0.180E-01	0.485214E 01	0.305610E-02	-0.359055E 02	0.137293E-01
0.200E-01	0.490990E 01	0.306477E-02	0.209329E 02	0.442170E-02
0.220E-01	0.478283E 01	0.304470E-02	-0.460435E 02	0.225027E-01
0.240E-01	0.494990E 01	0.306978E-02	0.606785E 02	0.370584E-01
0.260E-01	0.502270E 01	0.308069E-02	0.262498E 02	0.697826E-02
0.280E-01	0.491857E 01	0.306426E-02	-0.374784E 02	0.149998E-01
0.300E-01	0.499360E 01	0.307551E-02	0.270943E 02	0.742593E-02
0.320E-01	0.489795E 01	0.306042E-02	-0.344712E 02	0.126712E-01
0.340E-01	0.507159E 01	0.308643E-02	0.626846E 02	0.397179E-01
0.360E-01	0.508407E 01	0.308830E-02	0.447176E 01	0.203416E-03
0.380E-01	0.512247E 01	0.309405E-02	0.137550E 02	0.192553E-02
0.400E-01	0.500773E 01	0.307596E-02	-0.411027E 02	0.181131E-01
0.420E-01	0.510391E 01	0.309036E-02	0.345659E 02	0.121258E-01
0.440E-01	0.499112E 01	0.307258E-02	-0.404392E 02	0.175133E-01
0.460E-01	0.511802E 01	0.309158E-02	0.456306E 02	0.211185E-01
0.480E-01	0.499080E 01	0.307153E-02	-0.456048E 02	0.222703E-01
0.500E-01	0.502137E 01	0.307611E-02	0.109994E 02	0.122712E-02
0.520E-01	0.481850E 01	0.304414E-02	-0.733734E 02	0.571343E-01
0.540E-01	0.461616E 01	0.301226E-02	-0.739558E 02	0.574359E-01
0.560E-01	0.440487E 01	0.297897E-02	-0.781034E 02	0.633408E-01
0.580E-01	0.417859E 01	0.294331E-02	-0.846872E 02	0.735537E-01
0.600E-01	0.394318E 01	0.290621E-02	-0.892525E 02	0.806444E-01
0.620E-01	0.370350E 01	0.286845E-02	-0.920903E 02	0.847211E-01
0.640E-01	0.346172E 01	0.283035E-02	-0.941602E 02	0.873821E-01
0.660E-01	0.321891E 01	0.279209E-02	-0.958717E 02	0.893504E-01
0.680E-01	0.298205E 01	0.275476E-02	-0.947776E 02	0.861632E-01
0.700E-01	0.275587E 01	0.271912E-02	-0.916727E 02	0.795866E-01
0.720E-01	0.253625E 01	0.268451E-02	-0.901504E 02	0.759941E-01
0.740E-01	0.232006E 01	0.265045E-02	-0.898790E 02	0.745802E-01
0.760E-01	0.210565E 01	0.261666E-02	-0.902924E 02	0.743061E-01
0.780E-01	0.189218E 01	0.258303E-02	-0.910746E 02	0.746232E-01
0.800E-01	0.167922E 01	0.254947E-02	-0.920603E 02	0.752511E-01
0.820E-01	0.146655E 01	0.251596E-02	-0.931652E 02	0.760488E-01
0.840E-01	0.125972E 01	0.248336E-02	-0.917858E 02	0.728650E-01
0.860E-01	0.106469E 01	0.245263E-02	-0.876121E 02	0.655865E-01
0.880E-01	0.878832E 00	0.242334E-02	-0.844811E 02	0.602659E-01
0.900E-01	0.697596E 00	0.239479E-02	-0.833584E 02	0.579870E-01
0.920E-01	0.558535E 00	0.237287E-02	-0.645101E 02	0.344326E-01
0.940E-01	0.581184E 00	0.237653E-02	0.105506E 02	0.938997E-03
0.960E-01	0.495345E 00	0.236300E-02	-0.400057E 02	0.131813E-01
0.980E-01	0.561171E 00	0.237383E-02	0.307807E 02	0.796830E-02
0.100E 00	0.455006E 00	0.235690E-02	-0.495953E 02	0.202125E-01
0.102E 00	0.518027E 00	0.236708E-02	0.295493E 02	0.732937E-02
0.104E 00	0.405923E 00	0.234941E-02	-0.525393E 02	0.226126E-01

Table III. Continued

Model 40 Shot 572 10 psi

AREA1	VOLUME	TIME	PRESSURE	DENSITY
0.264E 00	0.370400E 01	0.200000E-02	0.147000E 02	0.333800E-02

TIME SECONDS	PRESSURE PSI	DEN3 UE-S2/F4	U2 FPS	DPT PSI
0.200E-02	0.175340E 01	0.256758E-02	0.720838E 03	0.417152E 01
0.400E-02	0.342911E 01	0.279385E-02	0.633425E 03	0.349113E 01
0.600E-02	0.496615E 01	0.300133E-02	0.541952E 03	0.273895E 01
0.800E-02	0.630456E 01	0.318247E-02	0.446425E 03	0.196972E 01
0.100E-01	0.741745E 01	0.333356E-02	0.355257E 03	0.130742E 01
0.120E-01	0.832068E 01	0.345634E-02	0.278258E 03	0.832226E 00
0.140E-01	0.903745E 01	0.355376E-02	0.214539E 03	0.509069E 00
0.160E-01	0.956032E 01	0.362480E-02	0.153078E 03	0.264910E 00
0.180E-01	0.987025E 01	0.366691E-02	0.893267E 02	0.916211E-01
0.200E-01	0.980531E 01	0.365722E-02	-0.185512E 02	0.438008E-02
0.220E-01	0.998746E 01	0.368195E-02	0.520865E 02	0.313762E-01
0.240E-01	0.988922E 01	0.366730E-02	-0.279389E 02	0.997056E-02
0.260E-01	0.100929E 02	0.369492E-02	0.580403E 02	0.390544E-01
0.280E-01	0.999089E 01	0.367971E-02	-0.289037E 02	0.107079E-01
0.300E-01	0.101906E 02	0.370677E-02	0.566746E 02	0.373480E-01
0.320E-01	0.100707E 02	0.368890E-02	-0.338546E 02	0.147324E-01
0.340E-01	0.102701E 02	0.371589E-02	0.564058E 02	0.370798E-01
0.360E-01	0.101447E 02	0.369723E-02	-0.352885E 02	0.160443E-01
0.380E-01	0.103386E 02	0.372345E-02	0.546831E 02	0.349239E-01
0.400E-01	0.102030E 02	0.370328E-02	-0.380570E 02	0.186942E-01
0.420E-01	0.103972E 02	0.372952E-02	0.546381E 02	0.349248E-01
0.440E-01	0.102468E 02	0.370717E-02	-0.421212E 02	0.229292E-01
0.460E-01	0.102746E 02	0.371093E-02	0.782096E 01	0.716487E-03
0.480E-01	0.997337E 01	0.366618E-02	-0.853004E 02	0.929922E-01
0.500E-01	0.963494E 01	0.361589E-02	-0.972471E 02	0.119119E 00
0.520E-01	0.927031E 01	0.356171E-02	-0.106450E 03	0.140484E 00
0.540E-01	0.890988E 01	0.350815E-02	-0.106833E 03	0.139365E 00
0.560E-01	0.858451E 01	0.345981E-02	-0.977149E 02	0.115072E 00
0.580E-01	0.829426E 01	0.341668E-02	-0.882143E 02	0.926719E-01
0.600E-01	0.800665E 01	0.337395E-02	-0.885162E 02	0.921388E-01
0.620E-01	0.770644E 01	0.332934E-02	-0.936651E 02	0.101774E 00
0.640E-01	0.740042E 01	0.328387E-02	-0.968219E 02	0.107241E 00
0.660E-01	0.709159E 01	0.323798E-02	-0.991116E 02	0.110783E 00
0.680E-01	0.678144E 01	0.319189E-02	-0.100986E 03	0.113358E 00
0.700E-01	0.648111E 01	0.314727E-02	-0.991614E 02	0.107788E 00
0.720E-01	0.619688E 01	0.310503E-02	-0.950948E 02	0.978274E-01
0.740E-01	0.592124E 01	0.306408E-02	-0.934433E 02	0.932233E-01
0.760E-01	0.565000E 01	0.302377E-02	-0.931751E 02	0.914715E-01
0.780E-01	0.538099E 01	0.298380E-02	-0.936493E 02	0.911804E-01
0.800E-01	0.511631E 01	0.294447E-02	-0.933696E 02	0.894437E-01
0.820E-01	0.485740E 01	0.290600E-02	-0.925391E 02	0.867163E-01
0.840E-01	0.460176E 01	0.286802E-02	-0.925809E 02	0.856599E-01
0.860E-01	0.434778E 01	0.283028E-02	-0.932135E 02	0.856884E-01
0.880E-01	0.409464E 01	0.279267E-02	-0.941573E 02	0.862651E-01
0.900E-01	0.384197E 01	0.275512E-02	-0.952723E 02	0.871262E-01
0.920E-01	0.359739E 01	0.271878E-02	-0.934452E 02	0.827211E-01
0.940E-01	0.337262E 01	0.268538E-02	-0.869060E 02	0.706971E-01
0.960E-01	0.316608E 01	0.265469E-02	-0.807630E 02	0.603747E-01
0.980E-01	0.296811E 01	0.262528E-02	-0.782685E 02	0.560796E-01
0.100E 00	0.277383E 01	0.259641E-02	-0.776674E 02	0.546154E-01
0.102E 00	0.258106E 01	0.256777E-02	-0.779193E 02	0.543633E-01
0.104E 00	0.238893E 01	0.253922E-02	-0.785367E 02	0.546130E-01

Table III. Continued

Model 40 Shot 577 20 psi

AREA1	VOLUME	TIME	PRESSURE	DENSITY
0.264E 00	0.370400E 01	0.200000E-02	0.147000E 02	0.421800E-02

TIME SECONDS	PRESSURE PSI	DEN3 UE-S2/F4	U2 FPS	DPT PSI
0.200E-02	0.230327E 01	0.262434E-02	0.905970E 03	0.649548E 01
0.400E-02	0.487529E 01	0.294184E-02	0.880733E 03	0.681123E 01
0.600E-02	0.757668E 01	0.326833E-02	0.818998E 03	0.651329E 01
0.800E-02	0.101186E 02	0.357555E-02	0.70267[illegible] 03	0.525825E 01
0.100E-01	0.123963E 02	0.385165E-02	0.584606E 03	0.393174E 01
0.120E-01	0.143195E 02	0.408603E-02	0.466082F 03	0.266084E 01
0.140E-01	0.159016E 02	0.427941E-02	0.366182E 03	0.172487E 01
0.160E-01	0.171821E 02	0.443602E-02	0.285523E 03	0.108922E 01
0.180E-01	0.181806E 02	0.455809E-02	0.216121E 03	0.642600E 00
0.200E-01	0.189017E 02	0.464617E-02	0.152552E 03	0.327305E 00
0.220E-01	0.193448E 02	0.470026E-02	0.922286E 02	0.121500E 00
0.240E-01	0.194820E 02	0.471698E-02	0.282618E 02	0.115161E-01
0.260E-01	0.195816E 02	0.472911E-02	0.204335E 02	0.603729E-02
0.280E-01	0.197499E 02	0.474959E-02	0.344197E 02	0.171662E-01
0.300E-01	0.198514E 02	0.476192E-02	0.206631E 02	0.620824E-02
0.320E-01	0.200195E 02	0.478233E-02	0.341146E 02	0.169578E-01
0.340E-01	0.201202E 02	0.479455E-02	0.203567E 02	0.605914E-02
0.360E-01	0.202502E 02	0.481030E-02	0.261849E 02	0.100461E-01
0.380E-01	0.201353E 02	0.479448E-02	-0.230912E 02	0.890080E-02
0.400E-01	0.204118E 02	0.482795E-02	0.556334E 02	0.453628E-01
0.420E-01	0.202099E 02	0.480018E-02	-0.404145E 02	0.273339E-01
0.440E-01	0.205198E 02	0.483766E-02	0.621851E 02	0.567629E-01
0.460E-01	0.203255E 02	0.481097E-02	-0.387565E 02	0.251912E-01
0.480E-01	0.203800E 02	0.481757E-02	0.109106E 02	0.175151E-02
0.500E-01	0.199338E 02	0.475629E-02	-0.899740E 02	0.134284E 00
0.520E-01	0.194936E 02	0.469583E-02	-0.899249E 02	0.132433E 00
0.540E-01	0.190560E 02	0.463574E-02	-0.905429E 02	0.132537E 00
0.560E-01	0.186234E 02	0.457633E-02	-0.906655E 02	0.131193E 00
0.580E-01	0.182019E 02	0.451845E-02	-0.894740E 02	0.126158E 00
0.600E-01	0.177904E 02	0.446193E-02	-0.884536E 02	0.121760E 00
0.620E-01	0.173833E 02	0.440603E-02	-0.886138E 02	0.120669E 00
0.640E-01	0.169782E 02	0.435039E-02	-0.893173E 02	0.121041E 00
0.660E-01	0.165621E 02	0.429324E-02	-0.929845E 02	0.129440E 00
0.680E-01	0.161268E 02	0.423346E-02	-0.986693E 02	0.143677E 00
0.700E-01	0.156799E 02	0.417210E-02	-0.102805E 03	0.153671E 00
0.720E-01	0.152276E 02	0.410999E-02	-0.105648E 03	0.159840E 00
0.740E-01	0.147727E 02	0.404752E-02	-0.107915E 03	0.164208E 00
0.760E-01	0.143213E 02	0.398552E-02	-0.108763E 03	0.164234E 00
0.780E-01	0.138922E 02	0.392659E-02	-0.104921E 03	0.150619E 00
0.800E-01	0.134915E 02	0.387156E-02	-0.993248E 02	0.133140E 00
0.820E-01	0.131056E 02	0.381857E-02	-0.969493E 02	0.125129E 00
0.840E-01	0.127272E 02	0.376659E-02	-0.964102E 02	0.122061E 00
0.860E-01	0.123522E 02	0.371511E-02	-0.968274E 02	0.121434E 00
0.880E-01	0.119791E 02	0.366386E-02	-0.977281E 02	0.121991E 00
0.900E-01	0.116068E 02	0.361274E-02	-0.988792E 02	0.123130E 00
0.920E-01	0.112439E 02	0.356290E-02	-0.977447E 02	0.118669E 00
0.940E-01	0.109046E 02	0.351631E-02	-0.925508E 02	0.105031E 00
0.960E-01	0.105875E 02	0.347276E-02	-0.875712E 02	0.928884E-01
0.980E-01	0.102806E 02	0.343061E-02	-0.857955E 02	0.880832E-01
0.100E 00	0.997808E 01	0.338906E-02	-0.856104E 02	0.866419E-01
0.102E 00	0.967738E 01	0.334777E-02	-0.861385E 02	0.866438E-01
0.104E 00	0.937749E 01	0.330658E-02	-0.869806E 02	0.872566F-01

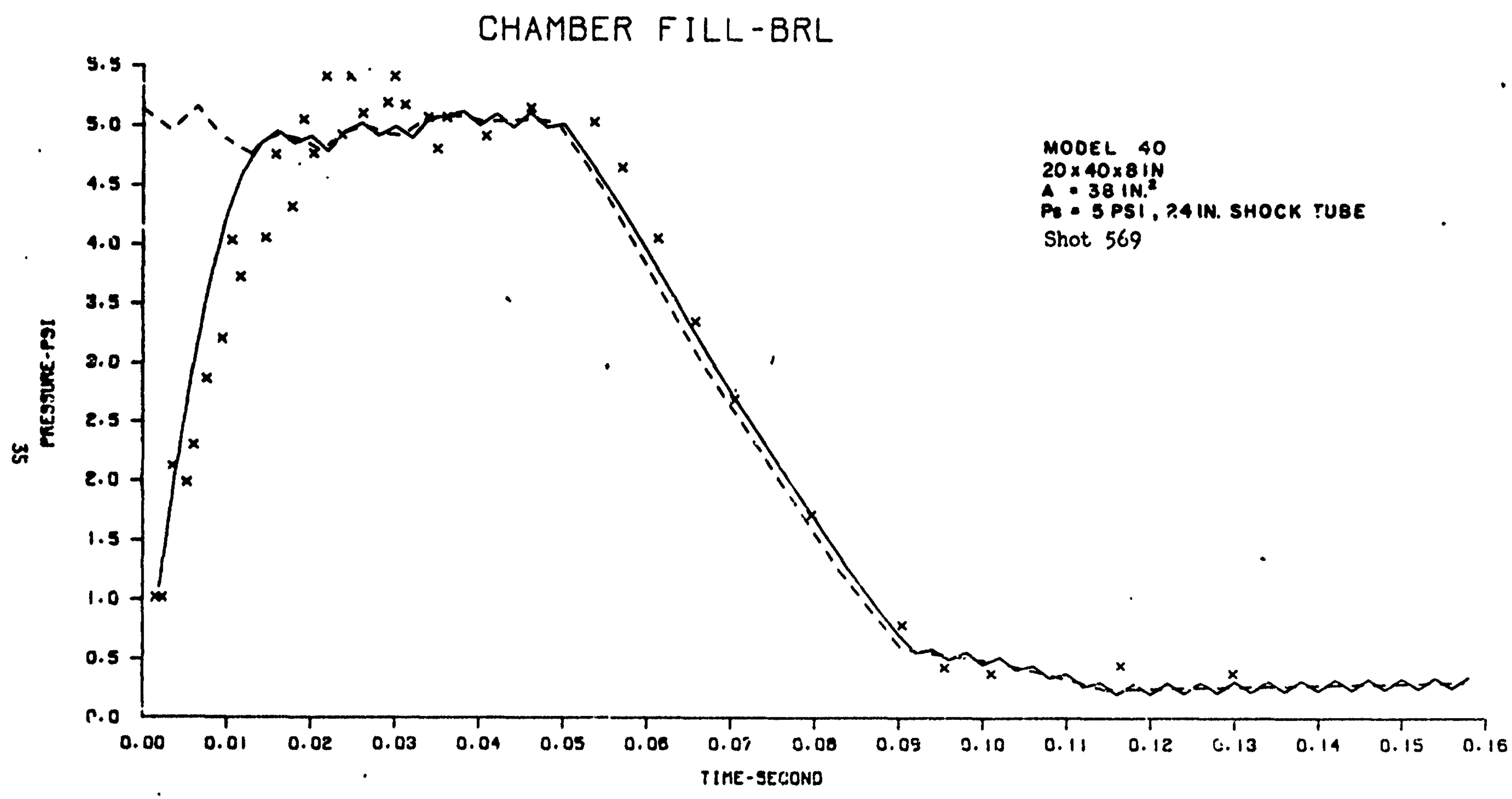


Figure 13. Fill Prediction for Model 40, Ps=5 psi

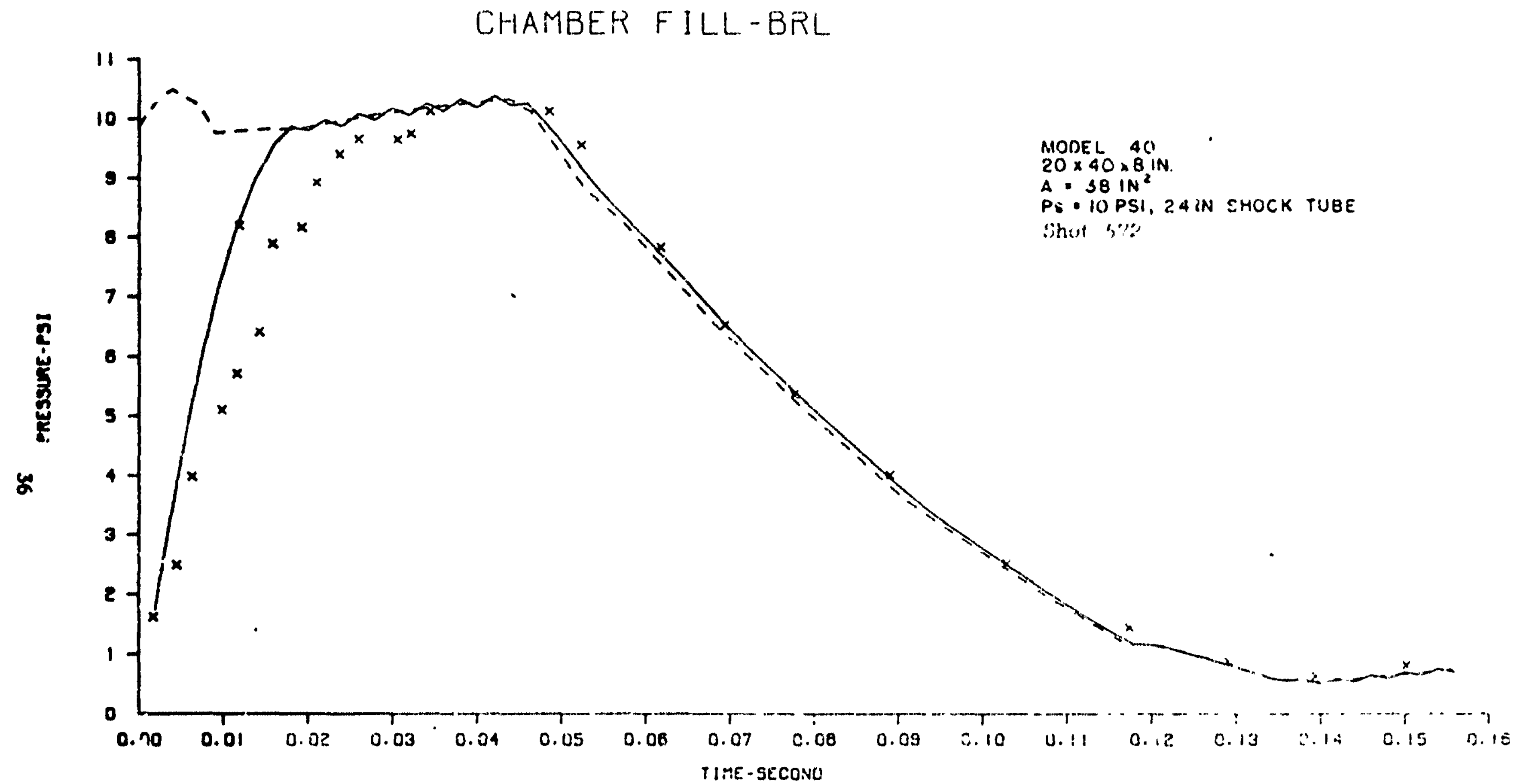


Figure 14. Fill Prediction for Model 40, Ps=10 psi

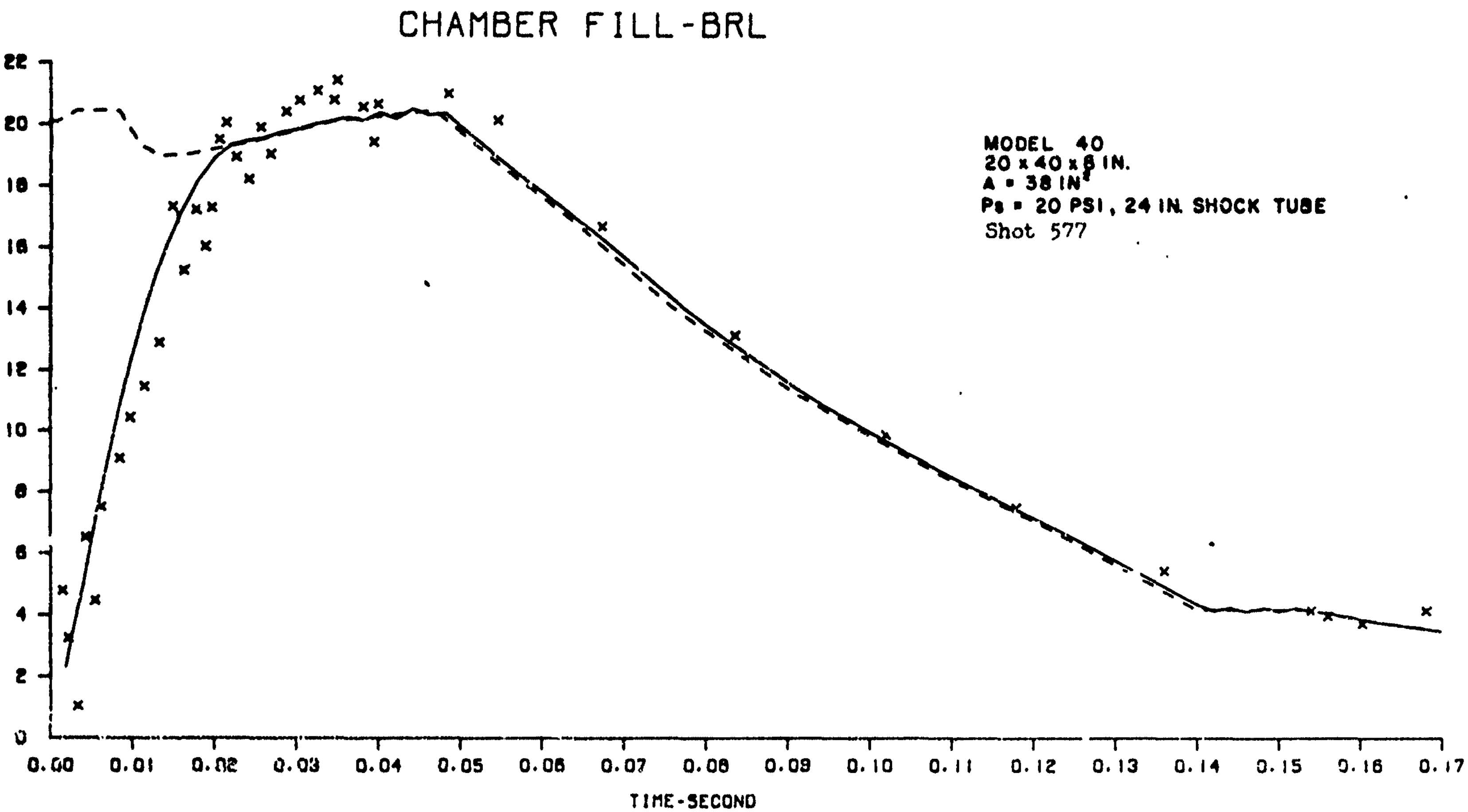


Figure 15. Fill Prediction for Model 40, Ps=20 psi

Table IV. Fill Parameters for Model 42

05 MAR 73 PAGE 1

MAR. 5,73 BRLESC2 FORTRAN. CT 16..47

TB-175 COULTER-BAITY CHFBRL 4911 1

Model 42

Shot 5-73-3 5psi

AREA	VOLUME	TIME	PRESSURE	DENSITY
0.549E 00	0.466750E 02	0.500000E-02	0.149800E 02	0.284400E-02

TIME SECONDS	PRESSURE PSI	DEN3 UE-S2/F4	U2 FPS	DPT PSI
0.500E-02	0.460720E 00	0.251603E-02	0.482794E 03	0.188320E 01
0.100E-01	0.903133E 00	0.257940E-02	0.453459E 03	0.169764F 01
0.150E-01	0.132236E 01	0.263947E-02	0.421309E 03	0.149532E 01
0.200E-01	0.171323E 01	0.269557E-02	0.386122E 03	0.127957E 01
0.250E-01	0.208153E 01	0.274843E-02	0.357763E 03	0.111726E 01
0.300E-01	0.243375E 01	0.279892E-02	0.336436E 03	0.100355E 01
0.350E-01	0.276846E 01	0.284686E-02	0.314770E 03	0.891372E 00
0.400E-01	0.308418E 01	0.289204E-02	0.292698E 03	0.781303E 00
0.450E-01	0.337939E 01	0.293427E-02	0.270127E 03	0.673886E 00
0.500E-01	0.365245E 01	0.297332E-02	0.246926E 03	0.569654E 00
0.550E-01	0.390253E 01	0.300908E-02	0.223760E 03	0.472741E 00
0.600E-01	0.412876E 01	0.304143E-02	0.200489E 03	0.383154E 00
0.650E-01	0.433007E 01	0.307022E-02	0.176921E 03	0.300918E 00
0.700E-01	0.450519E 01	0.309527E-02	0.152786E 03	0.226103E 00
0.750E-01	0.465593E 01	0.311683E-02	0.130670E 03	0.166452E 00
0.800E-01	0.478472E 01	0.313525E-02	0.111006E 03	0.120788E 00
0.850E-01	0.488729E 01	0.314992E-02	0.880057E 02	0.762746E-01
0.900E-01	0.495617E 01	0.315978E-02	0.588953E 02	0.342872E-01
0.950E-01	0.500188E 01	0.316631E-02	0.389807E 02	0.150615E-01
0.100E 00	0.504731E 01	0.317281E-02	0.386535E 02	0.148294E-01
0.105E 00	0.506263E 01	0.317500E-02	0.130201E 02	0.168531E-02
0.110E 00	0.501969E 01	0.316820E-02	-0.365100E 02	0.146715E-01
0.115E 00	0.501024E 01	0.316670E-02	-0.804541E 01	0.712003E-03
0.120E 00	0.505397E 01	0.317295E-02	0.371961E 02	0.137364E-01
0.125E 00	0.507049E 01	0.317531E-02	0.140323E 02	0.195801E-02
0.130E 00	0.503519E 01	0.316972E-02	-0.299900E 02	0.990544E-02
0.135E 00	0.505878E 01	0.317310E-02	0.200552E 02	0.399684E-02
0.140E 00	0.509157E 01	0.317778E-02	0.278288E 02	0.770227E-02
0.145E 00	0.507230E 01	0.317473E-02	-0.163375E 02	0.294416E-02
0.150E 00	0.504046E 01	0.316969E-02	-0.270455E 02	0.805601E-02
0.155E 00	0.503614E 01	0.316900E-02	-0.367194E 01	0.148391E-03
0.160E 00	0.506900E 01	0.317370E-02	0.279265E 02	0.775019E-02
0.165E 00	0.509002E 01	0.317670E-02	0.178333E 02	0.316411E-02
0.170E 00	0.510683E 01	0.317911E-02	0.142514E 02	0.202223E-02
0.175E 00	0.512456E 01	0.318164E-02	0.150128E 02	0.224540E-02
0.180E 00	0.514200E 01	0.318413E-02	0.147612E 02	0.217214E-02
0.185E 00	0.503172E 01	0.316668E-02	-0.942397E 02	0.971566E-01
0.190E 00	0.485373E 01	0.313851E-02	-0.155648E 03	0.258986E 00
0.195E 00	0.463446E 01	0.310381E-02	-0.196544E 03	0.402888E 00
0.200E 00	0.438473E 01	0.306430E-02	-0.229747E 03	0.536359E 00
0.205E 00	0.411691E 01	0.302192E-02	-0.252367E 03	0.631847E 00
0.210E 00	0.383970E 01	0.297805E-02	-0.266895E 03	0.691667E 00
0.215E 00	0.355443E 01	0.293291E-02	-0.280787E 03	0.748795E 00
0.220E 00	0.326225E 01	0.288667E-02	-0.294221E 03	0.803657E 00
0.225E 00	0.297262E 01	0.284084E-02	-0.296739E 03	0.803434E 00
0.230E 00	0.269413E 01	0.279677E-02	-0.288613E 03	0.751403E 00
0.235E 00	0.242611E 01	0.275436E-02	-0.280932E 03	0.703886E 00
0.240E 00	0.216794E 01	0.271351E-02	-0.273699E 03	0.660575E 00
0.245E 00	0.192440E 01	0.267497E-02	-0.260198E 03	0.592383E 00
0.250E 00	0.170067E 01	0.263957E-02	-0.240021E 03	0.502018E 00
0.255E 00	0.149634E 01	0.260724E-02	-0.220040E 03	0.420308E 00
0.260E 00	0.131106E 01	0.257792E-02	-0.200239E 03	0.346844E 00

Table IV. Continued

Model 42
Shot 5-73-" 10psi

AREA1	VOLUME	TIME	PRESSURE	DENSITY
0.586E 00	0.466700E 02	0.500000E-02	0.149100E 02	0.335400E-02

TIME SECONDS	PRESSURE PSI	DEN3 UE-S2/F4	U2 FPS	DPT PSI
0.500E-02	0.730345E 00	0.256482E-02	0.719278E 03	0.416995E 01
0.100E-01	0.154282E 01	0.266718E-02	0.677197E 03	0.383347E 01
0.150E-01	0.228462E 01	0.276669E-02	0.636490E 03	0.350320E 01
0.200E-01	0.300317E 01	0.286304E-02	0.597120E 03	0.318189E 01
0.250E-01	0.369592E 01	0.295590E-02	0.558883E 03	0.287014E 01
0.300E-01	0.436055E 01	0.304496E-02	0.521720E 03	0.256984E 01
0.350E-01	0.499565E 01	0.313004E-02	0.486067E 03	0.228725E 01
0.400E-01	0.560003E 01	0.321099E-02	0.451857E 03	0.202293E 01
0.450E-01	0.617110E 01	0.328747E-02	0.417929E 03	0.176792E 01
0.500E-01	0.670629E 01	0.335917E-02	0.384161E 03	0.152336E 01
0.550E-01	0.720484E 01	0.342598E-02	0.351591E 03	0.129906E 01
0.600E-01	0.766608E 01	0.348780E-02	0.320112E 03	0.109454E 01
0.650E-01	0.809345E 01	0.354508E-02	0.292223E 03	0.925674E 00
0.700E-01	0.849112E 01	0.359832E-02	0.268046E 03	0.789346E 00
0.750E-01	0.885904E 01	0.364755E-02	0.244820E 03	0.666589E 00
0.800E-01	0.919743E 01	0.369280E-02	0.222508E 03	0.556797E 00
0.850E-01	0.950257E 01	0.373358E-02	0.198566E 03	0.447918E 00
0.900E-01	0.977013E 01	0.376935E-02	0.172546E 03	0.341273E 00
0.950E-01	0.999974E 01	0.380004E-02	0.146925E 03	0.249380E 00
0.100E 00	0.101909E 02	0.382559E-02	0.121522E 03	0.171734E 00
0.105E 00	0.103429E 02	0.384590E-02	0.960844E 02	0.107950E 00
0.110E 00	0.104543E 02	0.386080E-02	0.701593E 02	0.578043E-01
0.115E 00	0.105222E 02	0.386987E-02	0.425709E 02	0.213491E-01
0.120E 00	0.105106E 02	0.386810E-02	-0.726031E 01	0.708252E-03
0.125E 00	0.105570E 02	0.387430E-02	0.290502E 02	0.995729E-02
0.130E 00	0.106004E 02	0.388009E-02	0.271313E 02	0.869658E-02
0.135E 00	0.106431E 02	0.388580E-02	0.266591E 02	0.840672E-02
0.140E 00	0.106857E 02	0.389148E-02	0.265354E 02	0.833885E-02
0.145E 00	0.107032E 02	0.389382E-02	0.109087E 02	0.141096E-02
0.150E 00	0.106746E 02	0.388947E-02	-0.177928E 02	0.427872E-02
0.155E 00	0.107073E 02	0.389387E-02	0.205489E 02	0.500511E-02
0.160E 00	0.106745E 02	0.388885E-02	-0.205580E 02	0.571134E-02
0.165E 00	0.107180E 02	0.389465E-02	0.270479E 02	0.867173E-02
0.170E 00	0.107382E 02	0.389734E-02	0.125347E 02	0.186461E-02
0.175E 00	0.107621E 02	0.390053E-02	0.149576E 02	0.262123E-02
0.180E 00	0.107838E 02	0.390342E-02	0.134774E 02	0.215827E-02
0.185E 00	0.107684E 02	0.390108E-02	-0.956703E 01	0.124040E-02
0.190E 00	0.107971E 02	0.390490E-02	0.178053E 02	0.376766E-02
0.195E 00	0.106656E 02	0.388493E-02	-0.821198E 02	0.907302E-01
0.200E 00	0.104621E 02	0.385402E-02	-0.129127E 03	0.220721E 00
0.205E 00	0.102212E 02	0.381743E-02	-0.155362E 03	0.314416E 00
0.210E 00	0.995781E 01	0.377742E-02	-0.172551E 03	0.381851E 00
0.215E 00	0.967418E 01	0.373433E-02	-0.188932E 03	0.450186E 00
0.220E 00	0.937200E 01	0.368843E-02	-0.204944E 03	0.520280E 00
0.225E 00	0.905886E 01	0.364086E-02	-0.216051E 03	0.568375E 00
0.230E 00	0.874060E 01	0.359252E-02	-0.223147E 03	0.596625E 00
0.235E 00	0.842181E 01	0.354410E-02	-0.226916E 03	0.607721E 00
0.240E 00	0.810642E 01	0.349619E-02	-0.227641E 03	0.603165E 00
0.245E 00	0.779816E 01	0.344937E-02	-0.225298E 03	0.583447E 00
0.250E 00	0.750053E 01	0.340416E-02	-0.219962E 03	0.550008E 00
0.255E 00	0.721022E 01	0.336006E-02	-0.217121E 03	0.529533E 00
0.260E 00	0.692418E 01	0.331661E-02	-0.216702E 03	0.520751E 00

Table IV. Continued

Model 42 Estimated 20psi

AREA1	VOLUME	TIME	PRESSURE	DENSITY
0.549E 00	0.466700E 02	0.500000E-02	0.148600E 02	0.421000E-02

TIME SECONDS	PRESSURE PSI	DEN3 UE-S2/F4	U2 FPS	DPT PSI
0.500E-02	0.958799E 00	0.258184E-02	0.905353E 03	0.651658E 01
0.100E-01	0.196370E 01	0.270766E-02	0.894151E 03	0.664663E 01
0.150E-01	0.301523E 01	0.283742E-02	0.882410E 03	0.676435E 01
0.200E-01	0.411371E 01	0.297104E-02	0.870124E 03	0.686839E 01
0.250E-01	0.522681E 01	0.310546E-02	0.838906E 03	0.666223E 01
0.300E-01	0.631807E 01	0.323725E-02	0.789633E 03	0.614792E 01
0.350E-01	0.738325E 01	0.336590E-02	0.742180E 03	0.564037E 01
0.400E-01	0.841857E 01	0.349093E-02	0.696529E 03	0.514506E 01
0.450E-01	0.942072E 01	0.361196E-02	0.652647E 03	0.466639E 01
0.500E-01	0.103868E 02	0.372863E-02	0.610487E 03	0.420778E 01
0.550E-01	0.113142E 02	0.384064E-02	0.569995E 03	0.377176E 01
0.600E-01	0.122010E 02	0.394773E-02	0.531104E 03	0.336011E 01
0.650E-01	0.130452E 02	0.404968E-02	0.493744E 03	0.297395E 01
0.700E-01	0.138454E 02	0.414632E-02	0.457837E 03	0.261385E 01
0.750E-01	0.146003E 02	0.423749E-02	0.423299E 03	0.227994E 01
0.800E-01	0.153090E 02	0.432307E-02	0.390044E 03	0.197201E 01
0.850E-01	0.159705E 02	0.440297E-02	0.357982E 03	0.168958E 01
0.900E-01	0.165842E 02	0.447709E-02	0.327020E 03	0.143197E 01
0.950E-01	0.171496E 02	0.454537E-02	0.297061E 03	0.119837E 01
0.100E 00	0.176663E 02	0.460777E-02	0.268007E 03	0.987915E 00
0.105E 00	0.181338E 02	0.466423E-02	0.239753E 03	0.799689E 00
0.110E 00	0.185518E 02	0.471471E-02	0.212188E 03	0.632794E 00
0.115E 00	0.189199E 02	0.475916E-02	0.185192E 03	0.486373E 00
0.120E 00	0.192377E 02	0.479754E-02	0.158626E 03	0.359645E 00
0.125E 00	0.195045E 02	0.482977E-02	0.132320E 03	0.251932E 00
0.130E 00	0.197196E 02	0.485574E-02	0.106039E 03	0.162698E 00
0.135E 00	0.198813E 02	0.487527E-02	0.793894E 02	0.916030E-01
0.140E 00	0.199865E 02	0.488797E-02	0.514625E 02	0.386201E-01
0.145E 00	0.200720E 02	0.489226E-02	0.173186E 02	0.438326E-02
0.150E 00	0.199800E 02	0.488637E-02	-0.204939E 02	0.713133E-02
0.155E 00	0.200232E 02	0.489159E-02	0.210934E 02	0.650137E-02
0.160E 00	0.199800E 02	0.488554E-02	-0.210496E 02	0.752207E-02
0.165E 00	0.200232E 02	0.489075E-02	0.210597E 02	0.648062E-02
0.170E 00	0.199800E 02	0.488470E-02	-0.210491E 02	0.752043E-02
0.175E 00	0.200232E 02	0.488991E-02	0.210618E 02	0.648194E-02
0.180E 00	0.199800E 02	0.488386E-02	-0.210510E 02	0.752053E-02
0.185E 00	0.200232E 02	0.488907E-02	0.210638E 02	0.648313E-02
0.190E 00	0.199800E 02	0.488302E-02	-0.210530E 02	0.752063E-02
0.195E 00	0.200232E 02	0.488823E-02	0.210657E 02	0.648432E-02
0.200E 00	0.199800E 02	0.488219E-02	-0.210549E 02	0.752072E-02
0.205E 00	0.200232E 02	0.488740E-02	0.210677E 02	0.648552E-02
0.210E 00	0.199800E 02	0.488135E-02	-0.210568E 02	0.752082E-02
0.215E 00	0.200232E 02	0.488656E-02	0.210696E 02	0.648671E-02
0.220E 00	0.199800E 02	0.488052E-02	-0.210588E 02	0.752091E-02
0.225E 00	0.200232E 02	0.488573E-02	0.210715E 02	0.648790E-02
0.230E 00	0.199800E 02	0.487969E-02	-0.210607E 02	0.752101E-02
0.235E 00	0.200232E 02	0.488490E-02	0.210735E 02	0.648909E-02
0.240E 00	0.199800E 02	0.487885E-02	-0.210626E 02	0.752110E-02
0.245E 00	0.200232E 02	0.488407E-02	0.210754E 02	0.649027E-02
0.250E 00	0.199800E 02	0.487802E-02	-0.210645E 02	0.752120E-02

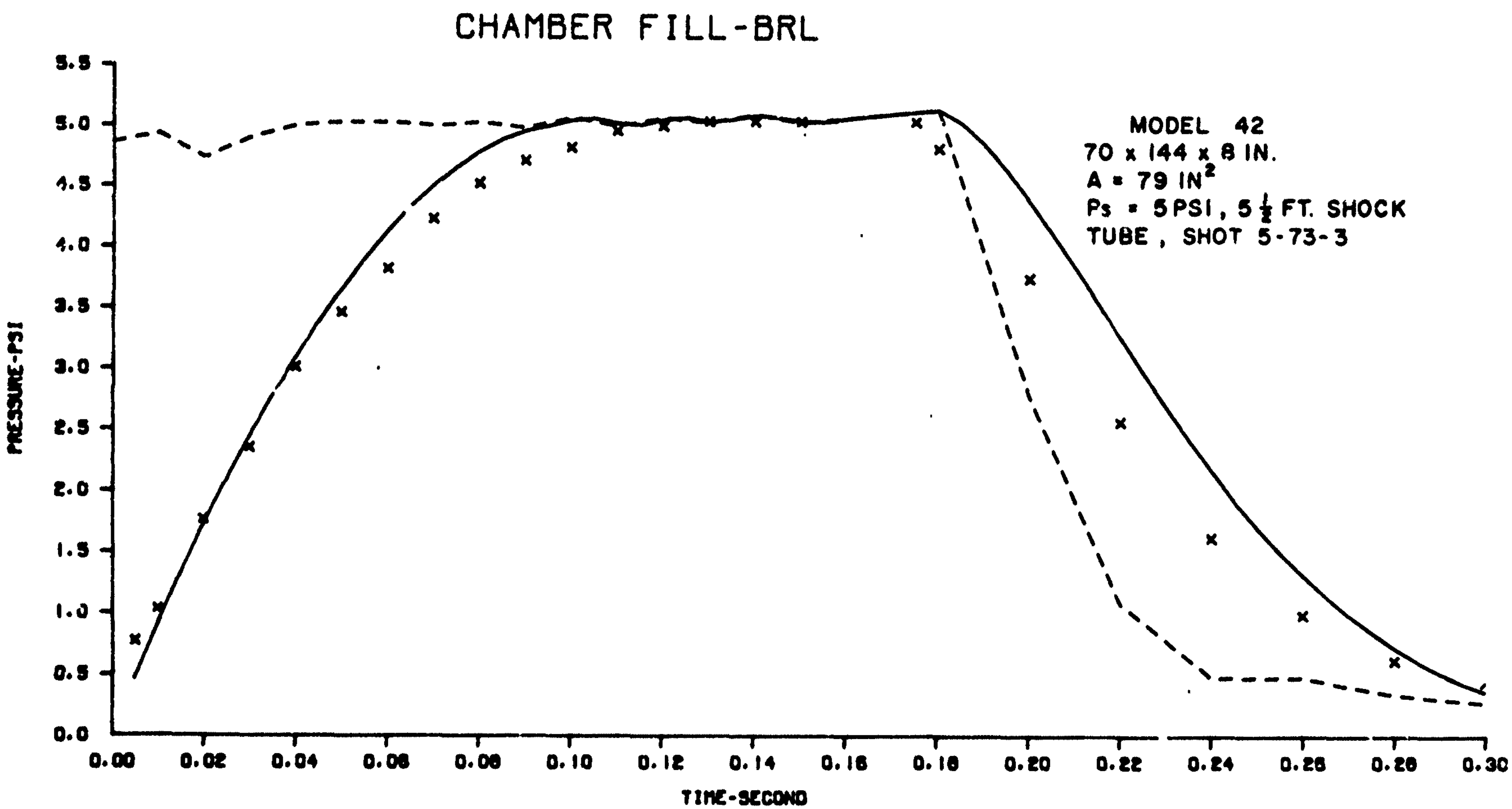


Figure 16. Fill Predictions for Model 42, Ps=5 psi

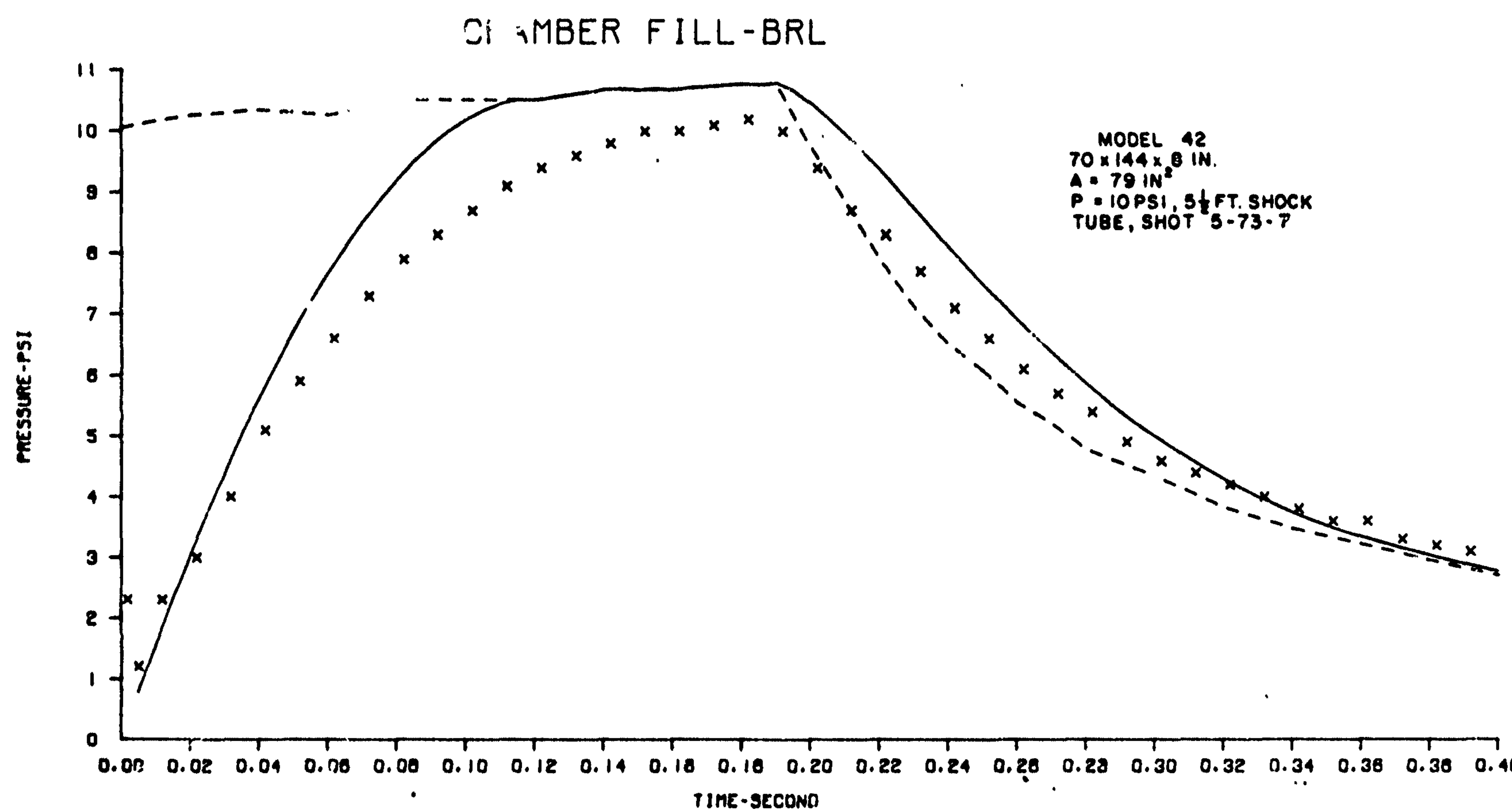
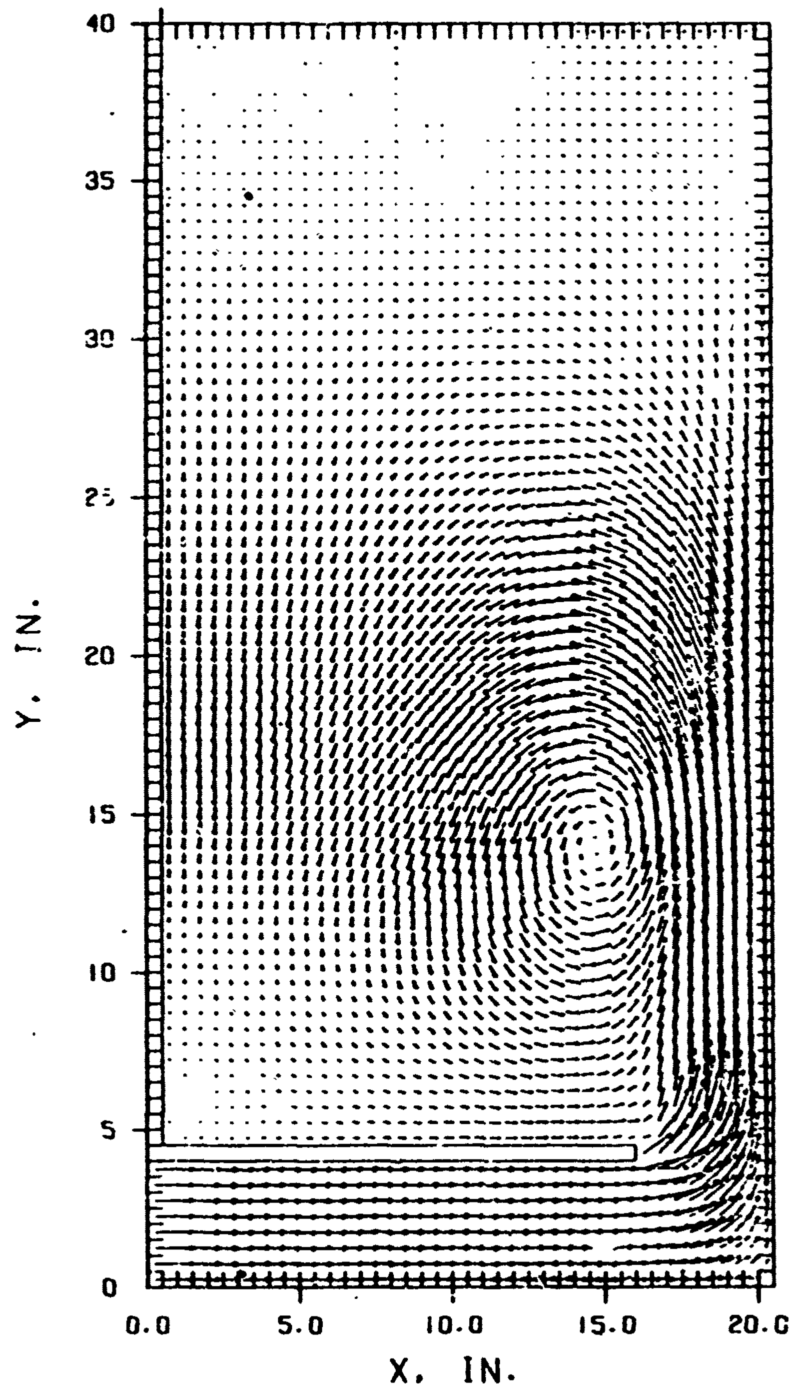


Figure 17. Fill Predictions for Model 42, Ps=10 psi



VELOCITY FIELD
TIME= 4.9670 MILLISEC CYCLE 450
VELOCITY VECTOR—→ EQUALS 430 FT/SEC
ZERO TIME IS TAKEN AS SHOCK FRONT ENTERS ROOM

Figure 18. RIPPLE Flow Predictions for Model 40

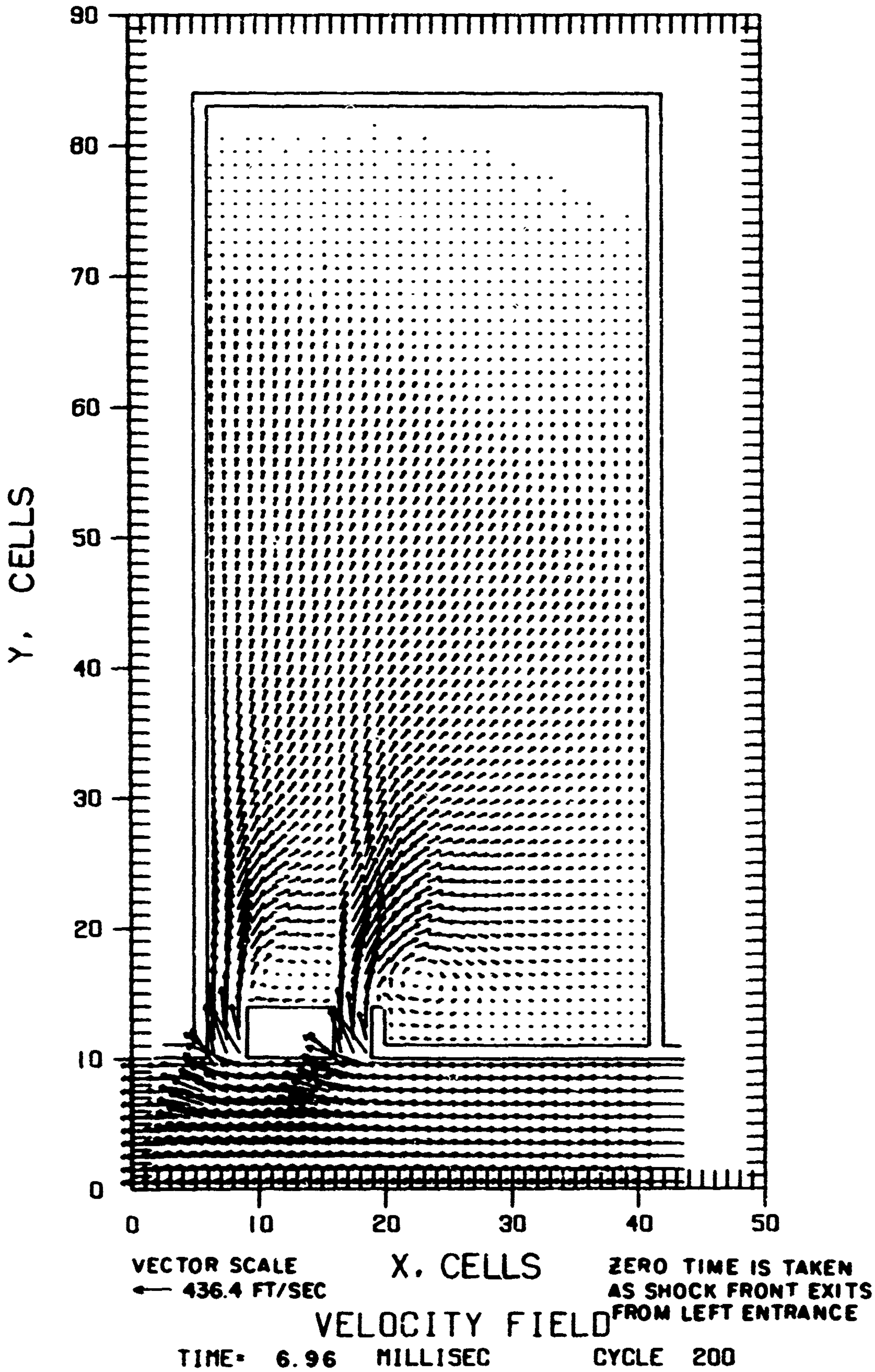


Figure 19. RIPPLE Flow Predictions for Model 42

The force exerted by the air flow upon the cylinder is written as Equation (1).

$$F = C_D\ A_c\ Q, \text{ where} \tag{1}$$

C, is the experimentally determined coefficient of drag as a function of the air flow Mach number, A_C is the projected cross-sectional area of the cylinder, and Q is the dynamic pressure of the air flow, found from Equation (2).

$$Q = 1/2\ \rho \upsilon^2, \text{ where} \tag{2}$$

both the density, ρ, and the air speed, υ, were allowed to vary as in Equation (3) and (4).

$$\rho = \rho_1 + (\rho_{fill} - \rho_1)\ t/t_{fill}; \tag{3}$$

here ρ_1 is the ambient density before filling the room and ρ_{fill} is the air density to which it fills. The ratio, t/t_{fill}, is elapsed time to total fill time for the room. ρ was varied in a similar way.

$$\upsilon = \upsilon_{max} - (\upsilon_{max})\ t/t_{fill}, \tag{4}$$

where υ_{max} is the initial maximum air speed as filling begins and goes to zero when the room has filled. The equations are not valid for times greater than the fill time.

The coefficient of drag varied as Equation (5).

$$C_D = C_{max} - (C_{max} - C_1)\ t/t_{fill}, \tag{5}$$

where C_{max} is the value for maximum air speed and C_1 is the lower limit for the minimum drag coefficient. These values are plotted as Figure 20. See also Ref. 5 and 6.

Acceleration is then given by

$$a = C_D\ Q\ A_C/m, \text{ where} \tag{6}$$

m is the mass of the cylinder exposed to the flow. Incremental calculations for velocity and displacement can be made for a time Δt. A value of Δt about equal to $t_{fill}/20$ gives sufficiently closed-spaced values for the motion parameters.

Predictions of the cylinders motion for each model tested, and also for an example of a full size basement shelter, are given for input shock over pressures of 5-20 psi. Those for the models are shown in Tables V and VI and Fig. 21-26. Predictions for the full size basements are given in Appendix F.

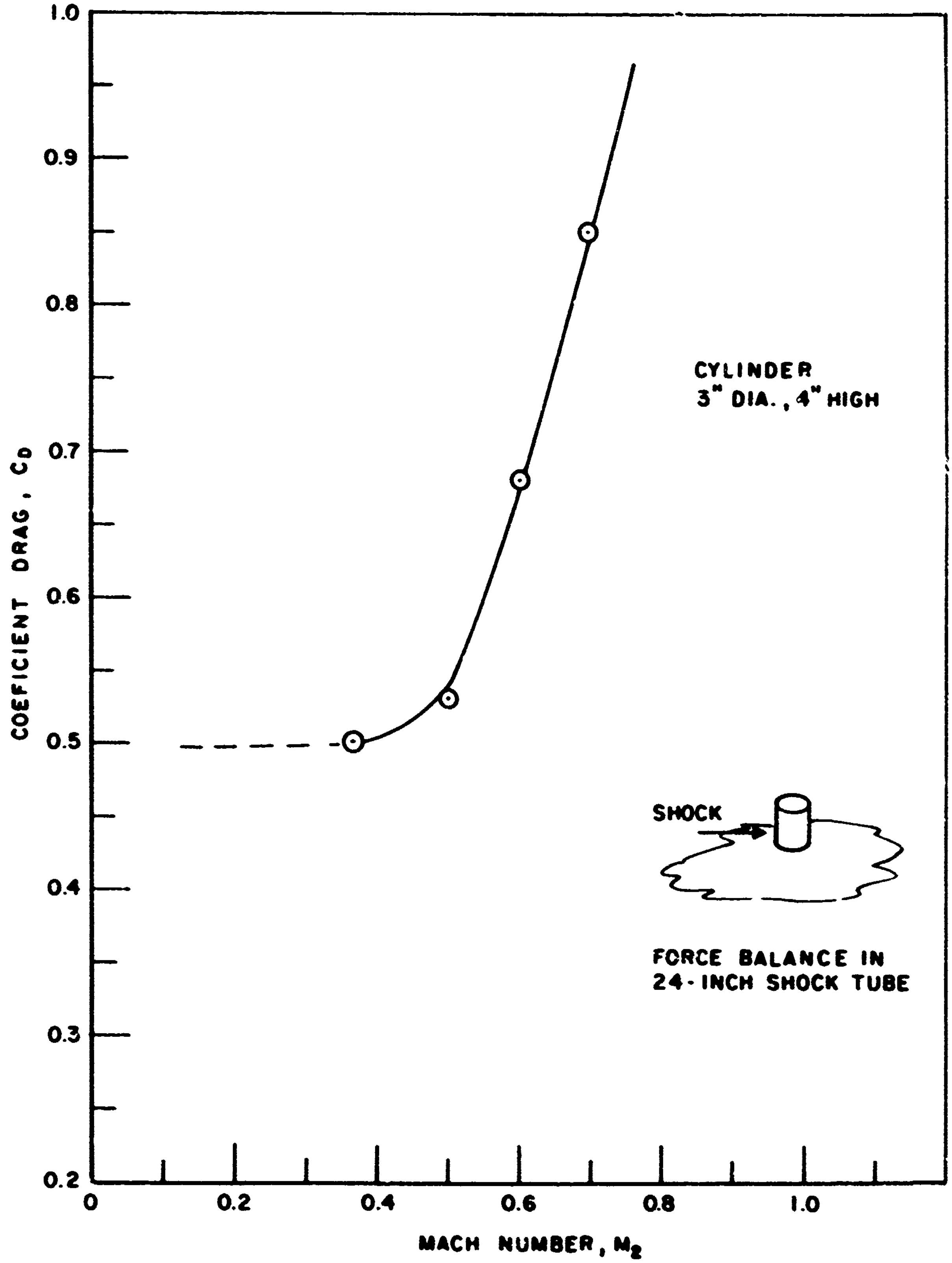


Figure 20. Coefficient of Drag for a Cylinder

Table V. Motion Predictions for Model 40

Shot 569 5 psi

Time,sec	Distance,ft	Velccity, ft/sec	Acceleration, ft/sec^2
.00100	.00066	.00000	669.86310
.00200	.00192	.66986	586.93502
.00300	.00369	1.25679	509.69365
.00400	.00589	1.76649	438.07990
.00500	.00847	2.20457	372.03910
.00600	.01136	2.57661	311.52094
.00700	.01450	2.88813	256.47934
.00800	.01785	3.14461	206.87238
.00900	.02137	3.35148	162.66228
.01000	.02501	3.51414	123.81519
.01100	.02873	3.63796	90.30166
.01200	.03252	3.72826	62.09557
.01300	.03635	3.79035	39.17513
.01400	.04020	3.82953	21.52228
.01500	.04407	3.85105	9.12284
.01600	.04793	3.86017	1.56641
.01700	.05179	3.86214	.04640

Shot 572 10 psi

.00100	.00208	.00000	2080.58493
.00200	.00600	2.08058	1842.66474
.00300	.01155	3.92324	1623.10544
.00400	.01851	5.54635	1421.04520
.00500	.02672	6.96740	1235.66792
.00600	.03598	8.20306	1066.19946
.00700	.04617	9.26926	911.90399
.00800	.05712	10.18117	772.08078
.00900	.06872	10.95325	646.06114
.01000	.08085	11.59931	533.20560
.01100	.09342	12.13251	432.90132
.01200	.10633	12.56542	344.55968
.01300	.11950	12.90998	267.61405
.01400	.13288	13.17759	201.51766
.01500	.14641	13.37911	145.74168
.01600	.16003	13.52485	99.77341
.01700	.17372	13.62462	63.11456
.01800	.18744	13.68774	35.27967
.01900	.20118	13.72302	15.79463
.02000	.21493	13.73881	4.19530
.02100	.22867	13.74301	.02617

Shot 577 20 psi

.00200	.01307	4.53156	4013.64942
.00400	.04035	12.08453	3105.80021
.00600	.07850	17.90085	2351.08489
.00800	.12478	22.27722	1731.04238
.01000	.17696	25.47468	1229.60016
.01200	.23324	27.72315	832.58625
.01400	.29222	29.22496	527.33311
.01600	.35284	30.15779	302.35347
.01800	.41434	30.67677	147.07270
.02000	.47622	30.91630	51.60671
.02200	.53821	30.99127	6.57681
.02400	.60021	30.99799	2.95563

Table VI. Motion Predictions for Model 42

Shot 5-73-3 5psi

Time,sec	Distance,ft	Velocity,ft/sec	Accel.,ft/sec^2
.01000	.04897	3.39113	602.63160
.02000	.15133	9.06674	467.54344
.03000	.29456	13.44227	352.33537
.04000	.46807	16.71229	255.39463
.05000	.66301	19.05603	175.40402
.06000	.87220	20.64017	111.30242
.07000	1.08997	21.62139	62.25415
.08000	1.31214	22.14851	27.62541
.09000	1.53596	22.36449	6.96681
.10000	1.76004	22.40824	.00107

Shot 5-73-6 10psi

Time,sec	Distance,ft	Velocity,ft/sec	Accel.,ft/sec^2
.01000	.15824	10.98767	1934.70696
.02000	.48692	29.15310	1485.78838
.03000	.94553	43.05478	1122.58405
.04000	1.50135	53.50815	829.48486
.05000	2.12804	61.18249	594.56092
.06000	2.80460	66.63500	408.57068
.07000	3.51456	70.33584	264.26611
.08000	4.24533	72.68668	155.89590
.09000	4.98765	74.03469	78.84369
.10000	5.73521	74.68322	29.35989
.11000	6.48432	74.89987	4.35925
.12000	7.23358	74.92276	1.26504

Estimated 20psi

Time,sec	Distance,ft	Velocity,ft/sec	Accel.,ft/sec^2
.01000	.33799	23.61066	4075.55450
.02000	1.02925	61.56092	3025.93824
.03000	1.98177	89.68717	2235.97704
.04000	3.12518	110.31112	1611.90000
.05000	4.40539	125.17205	1139.80640
.06000	5.78092	135.60571	778.63024
.07000	7.22017	142.66057	505.83806
.08000	8.69354	147.17569	304.70235
.09000	10.20154	149.83377	162.51672
.10000	11.71566	151.19813	69.39162
.11000	13.23348	151.73856	17.41764
.12000	14.75198	151.84956	.06669

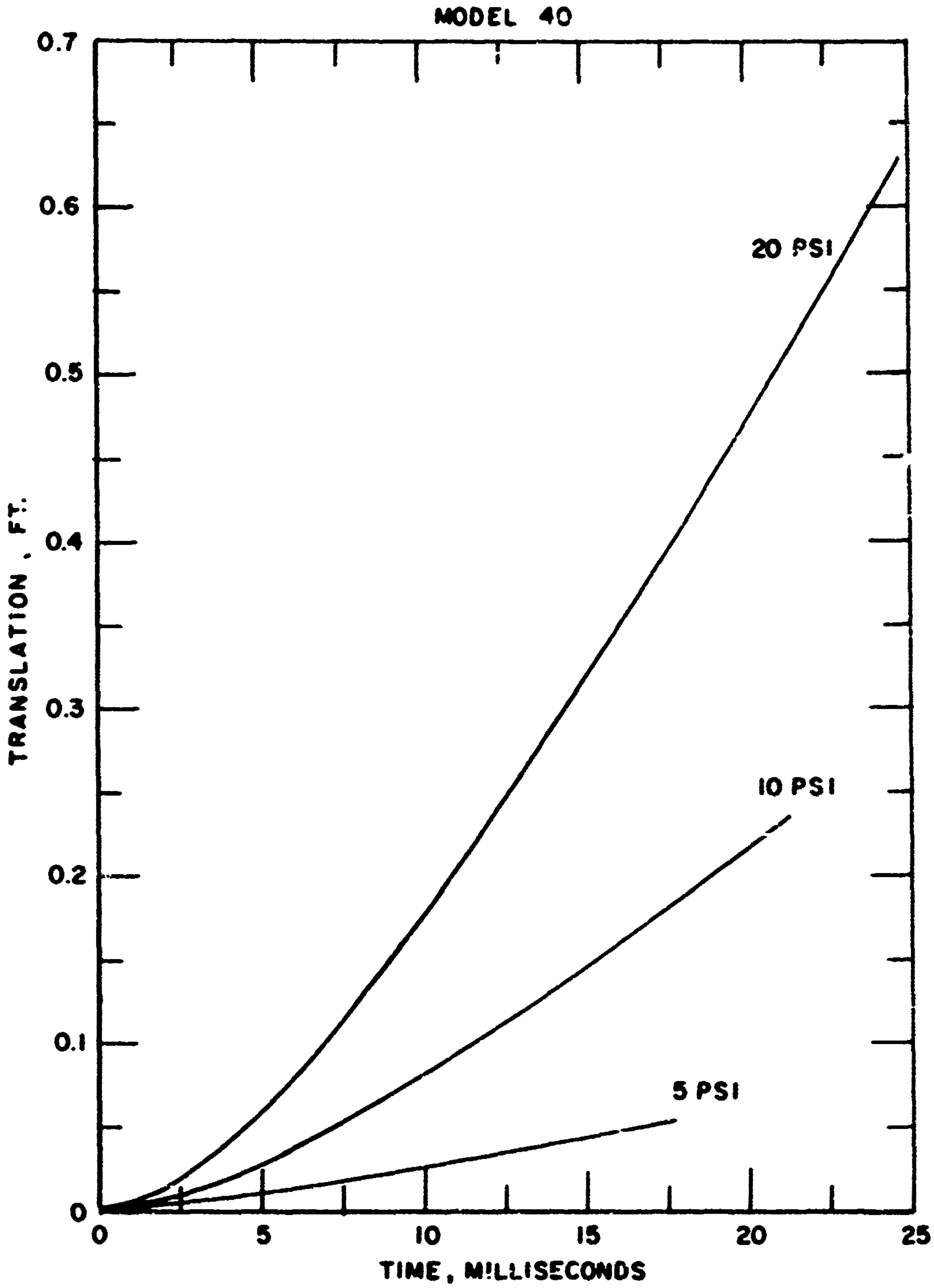


Figure 21. Predicted Translation for Cylinder-Model 40

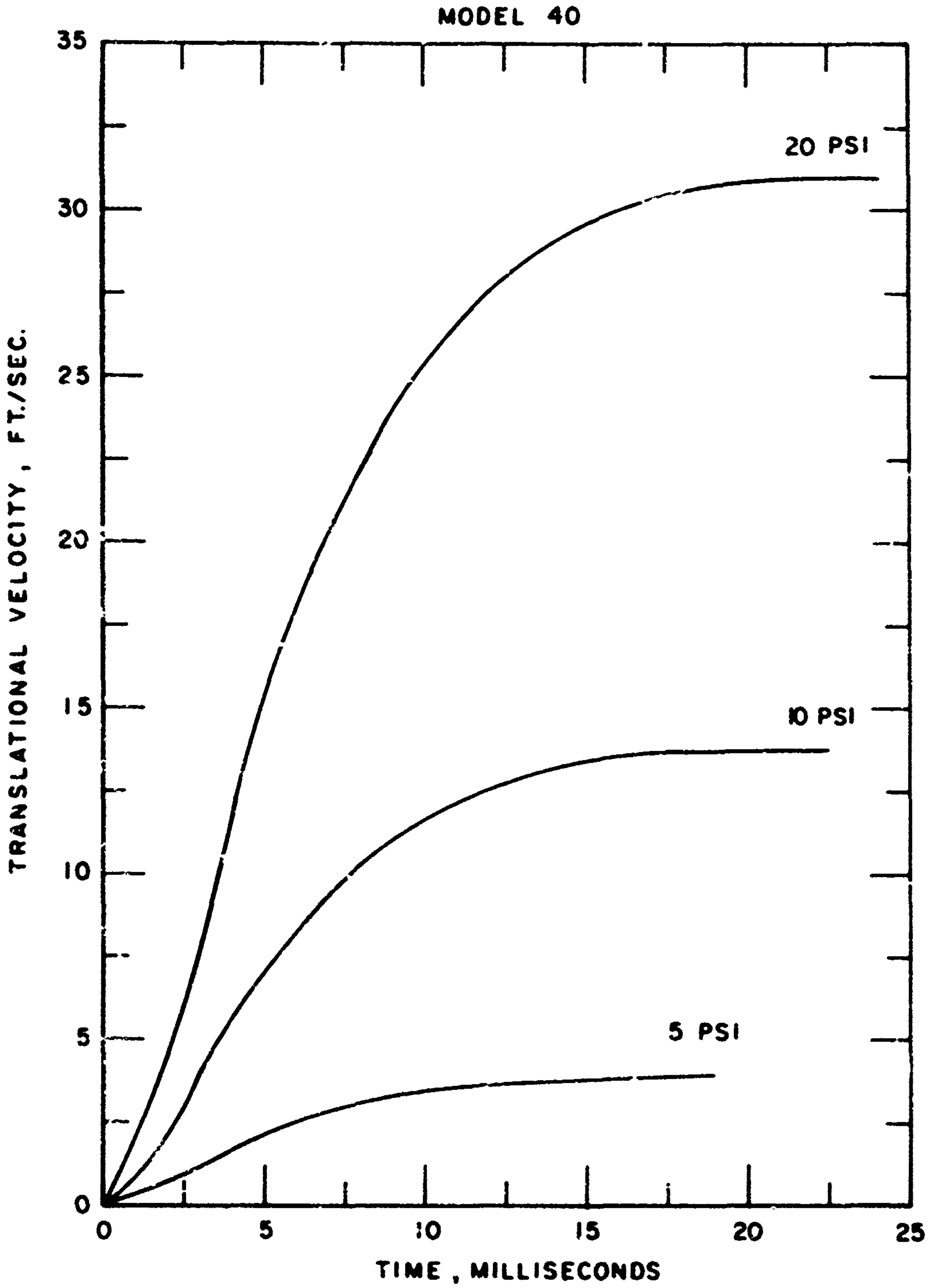


Figure 22. Predicted Translation Velocity for Cylinder-Model 40

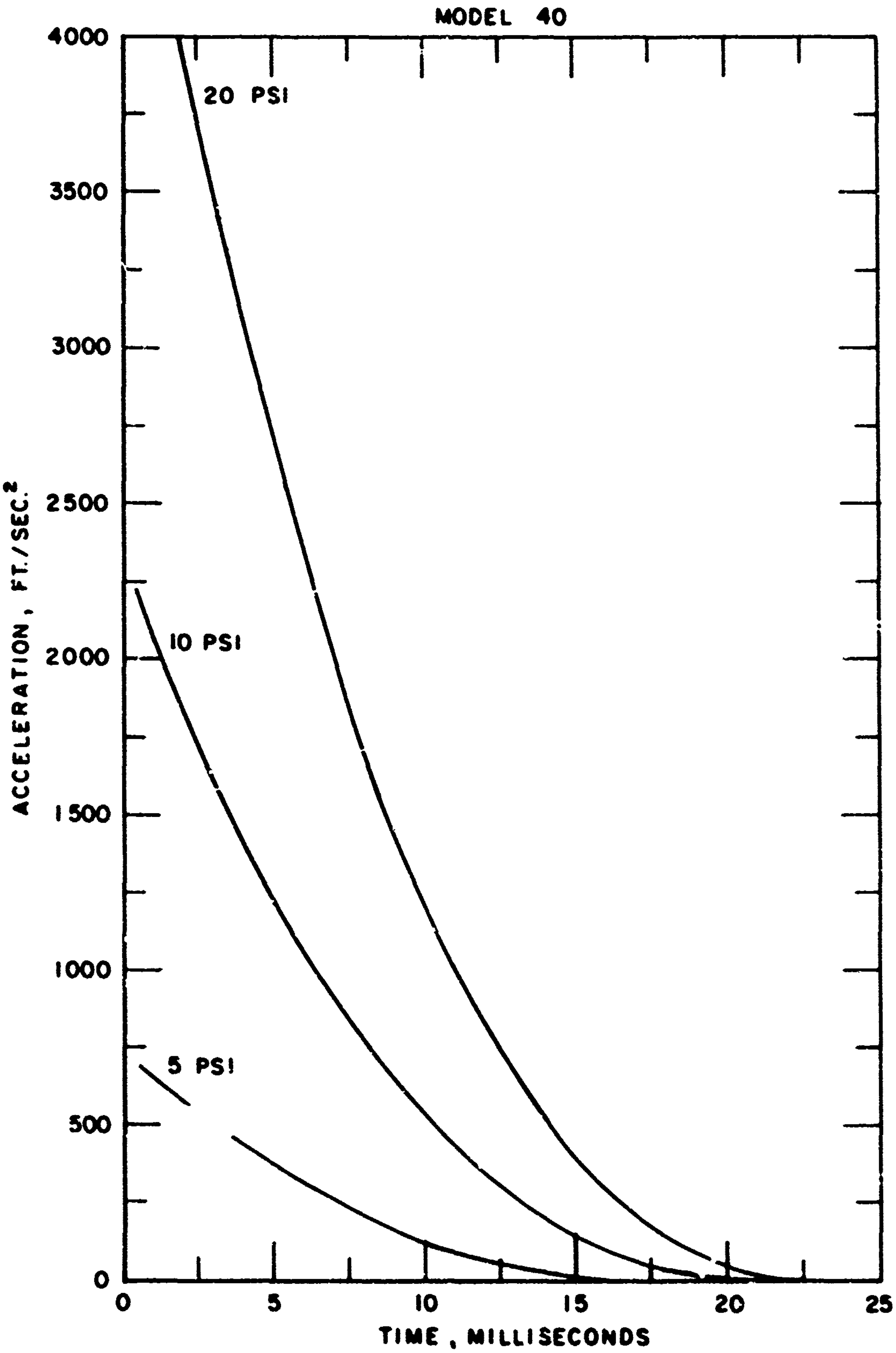


Figure 23. Predicted Acceleration for Cylinder - Model 40

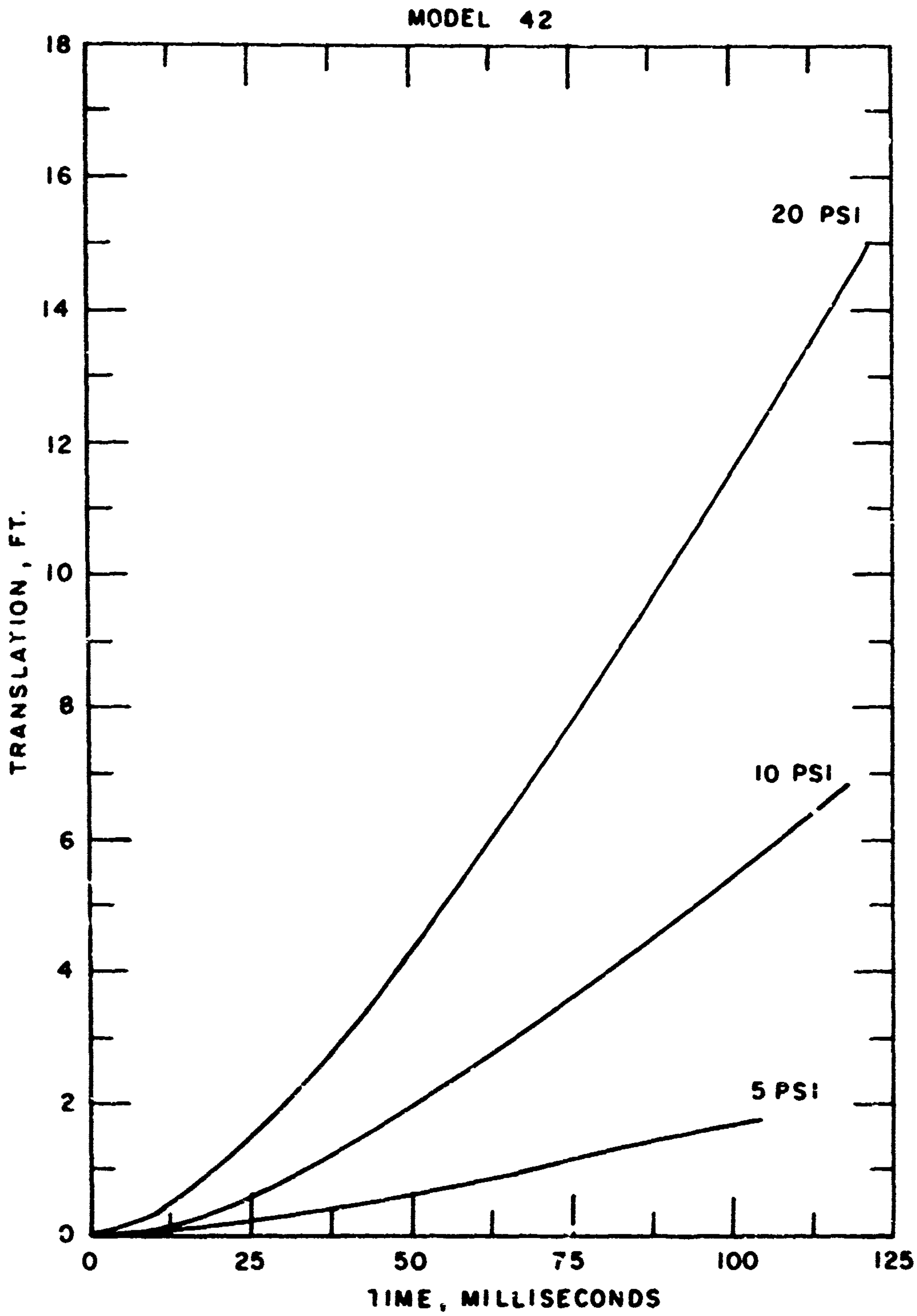


Figure 24. Predicted Translation for Cylinder-Model 42

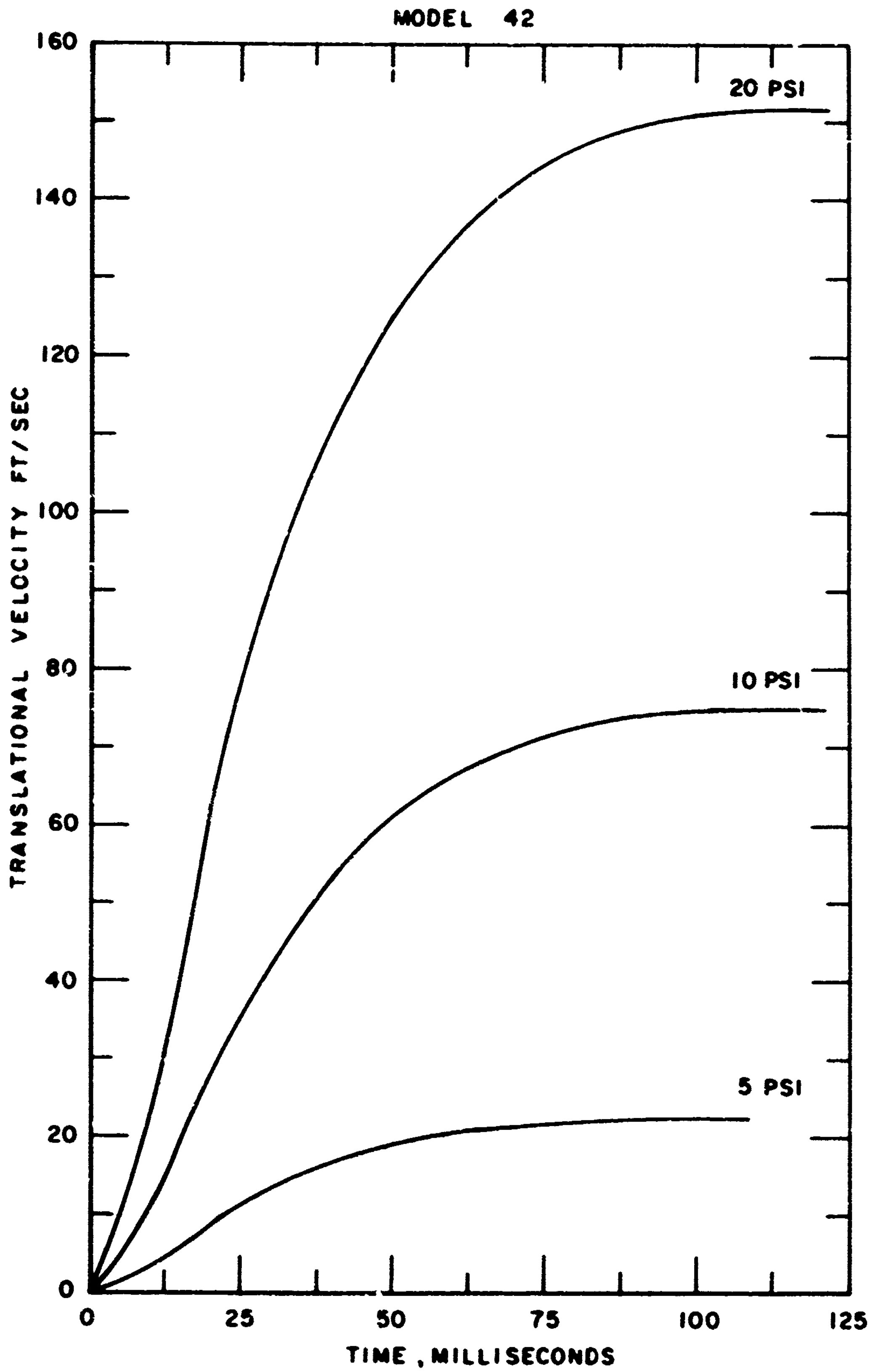


Figure 25. Predicted Translation Velocity for Cylinder-Model 42

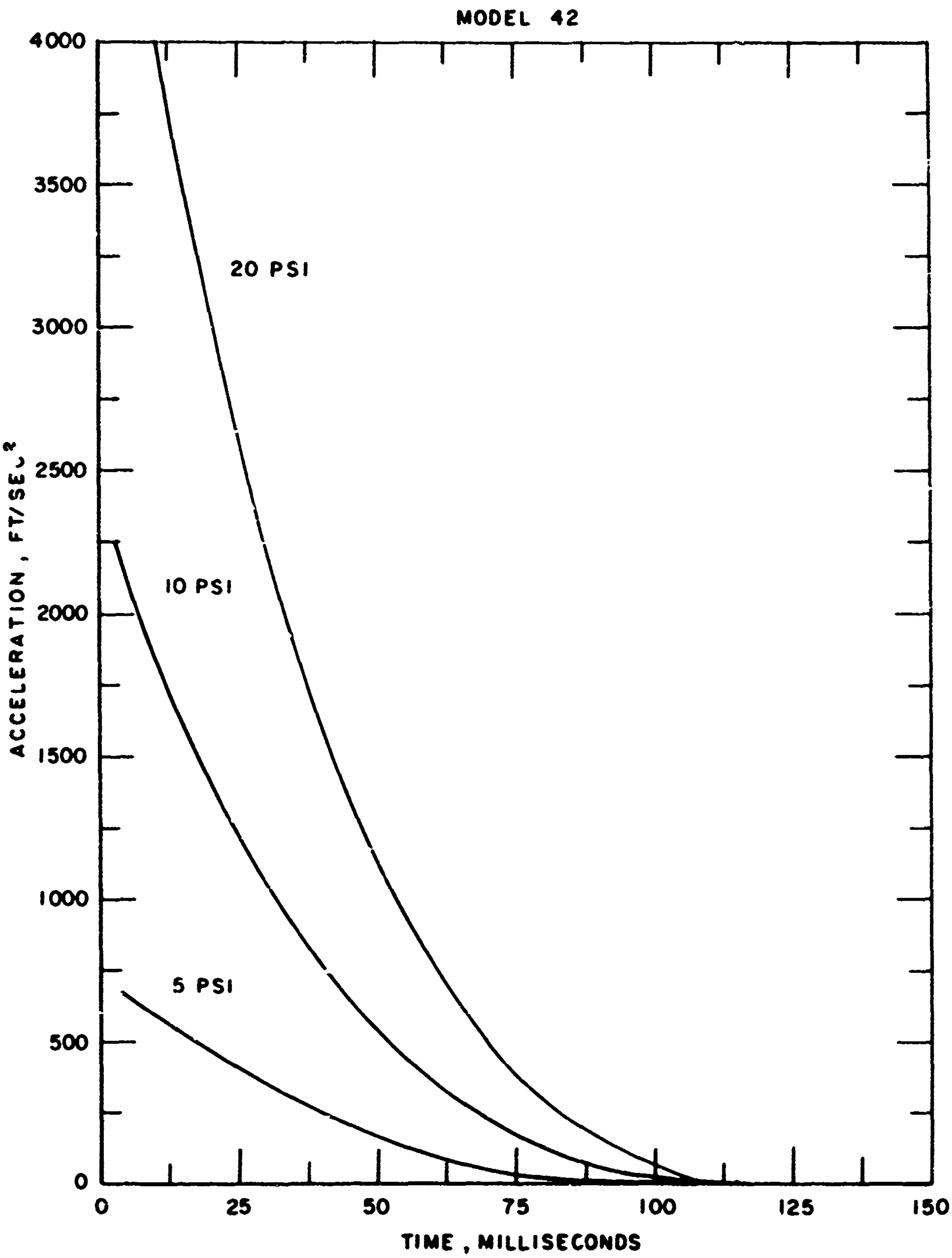


Figure 26. Predicted Acceleration for Cylinder-Model 42

V. SUMMARY AND CONCLUSIONS

Results obtained from the exposure of two 1/12th scale model basement shelters to shock waves are summarized in Part A. The results obtained and conclusions reached from the experiments are applied in Part B to several cases of full size basement shelters.

A. Summary of Experiments

Two 1/12th scale models of basement shelters were built to simulate full size basements which would hold a maximum of 80 and 1000 shelterees. The models were then exposed to range of input shock waves, P_s = 5-20 psi, from the BRL Shock Tubes.

Small nylon cylinders were placed inside the models and exposed at various floor locations, including areas of high speed air flow. High speed photography was used to record the motion of the cylinders during the air flow into the models from the shock tubes.

Predictions of the interior flows within the model were made by computer codes with two-dimensional assumptions. These were found to represent sufficiently the results from the actual three-dimensional models tested.

A general trend was observed from a study of the two scaled models. For an increase in the V/A ratio, there was a corresponding increase in flow duration available for translation of objects inside the shelter. A scaled duration is assumed for the input shock waves. This is illustrated by comparing the V/A values and the translation calculations for the two models. Model 40 has a V/A of 14 feet and Model 42 one of 85 feet, a factor of 6 between the two. The calculated filling times are 17 msec and 100 msec respectively, a factor of 5.9. A set of maximum translation velocities for a cylinder in the midst of the incoming flow for 5 psi input was found experimentally to be 2.9 ft/sec and 14.7 ft/sec respectively, a factor of about 5. This is somewhat less than the other factors shown, but does illustrate that the maximum translation is closely related to the V/A and fill times for a shelter. Predictions are given in Part B, following this trend, for several sizes of basement shelters.

B. Predictions for Full Size Basement Shelters

Prediction of filling curves of pressure in four basement shelter sizes (20 x 40 x 8 feet, 30 x 60 x 8 feet, 40 x 80 x 8 feet, and 70 x 144 x 8 feet) are given in Appendix F. At 10 ft^2/shelteree, the shelters would accomadate a maximum of about 80, 180, 320 and 1000 shelterees, respectively. The basement shelters are listed in Table VII.

The pressure-time fill predictions were made from the BRL Filling Code, Ref. 1, for input pressures of 3, 5, 10, 15 and 20 psi. The blast waves are assumed to have come from a 1-MT explosion, calculated from Ref.7.

Table VII. Dimensions of Models and Basements

Model or Basement	P_s,psi	Size	A,Ft^2	V/A,Ft	T_{fill},sec	Remarks
Model 40	5	20x40x8 in.	38 in.^{2}	14	.017	Nylon cylinder 1.28" dia x 1.83" high, 0.098 lb. weight.
	10				.021	
	20				.024	
Model 42	5	70x144x8 in.	80 in.^{2}	84	.105	
	10				.125	
	20					
Basement I	3	20x40x8 ft.	40	160	.135	Water drum 15 3/4" dia. x 22" high, 156 lb. weight, for I-IV.
	5				.150	
	10				.180	
	15				.195	
	20				.205	
Basement II	3	30x60x8 ft.	40	360	270	A 1-MT blast is assumed for full size basements, I-IV.
	5				.300	
	10				.360	
	15				.375	
	20				.375	
Basement III	3	40x80x8 ft.	40	640	.450	
	5				.500	
	10				.525	
	15				.550	
	20				.575	
Basement IV	3	70x144x8 ft.	80	1008	.600	
	5				.675	
	10				.725	
	15				.725	
	20				.725	

The flow parameters from the fill predictions; along with size, weight and coefficient of drag; were used to predict the translation of a 156 pound cylinder 15 3/4 inches diameter x 22 inches high. In addition, the fill parameters for the fourth basement were used to calculate the translation for a 170 pound cylinder in order to exactly match the cylinders used with Model 42.

The pressure-time filling curves and tables of corresponding motion parameters for the full size basement shelters are given in Appendix F. The parameters given are maximum since the maximum incoming flow parameters are used. Floor friction and gravity are neglected in the given predictions.

The calculations of translation for the cylinders were stopped at times corresponding to the time for the basements to fill to the outside blast pressure. The translation velocities were assumed maximum at the times of fill. The cylinders were assumed to continue at these maximum predicted velocities until the rear or other basement wall was struck. As mentioned above, hitting the floor or ceiling was assumed not to slow the cylinder, although the tumbling rate was experimentally observed to increase after such an impact of a nylon cylinder with the wooden floor of the basement models. Gravity and friction would of course act to decrease these maximum values for some objects.

Table VIII illustrates the scaling comparison for Model 42 and the simulated full size basement shelter. Also, the effect of a change in input blast wave shape is shown for comparison. The translation parameters have been calculated for these conditions. Figure 27 shows the maximum translation velocity predicted for a cylinder in each of these situations as a function of fraction of fill time. The scaled model and full size basements are shown with the lower curve illustrating the decreased velocity because of the exponential type blast wave used for the input. The present experiments with flat shock waves overestimate the maximum velocity when applied to a true field situation with an exponentially decaying blast wave.

Figures 28 and 29 illustrate input pressure dependence and V/A effect upon possible object translation at the end of fill time. For example, for the [illegible]-MT blast wave assumed, to stay below some maximum translational velocity of say 20 ft/sec, the limits would be 10 psi input for a shelter with a V/A of slightly less than 500 feet. Similar graphs may be plotted for other input blast conditions and V/A ratios. In this manner, maximum effects might be calculated for any given basement shelter situation.

Table VIII. Prediction of Translation for a Cylinder

A. Model 42--70x144x8 in.--Entrance, 80 in^2

1.56 oz. cylinder, 1.28 in. dia x 1.83 in. high

5 psi 5 1/2 ft. shock tube

Time,sec	Distance,ft	Velocity, ft/sec	Acceleration,ft/sec^2
.01000	.04570	3.16880	560.53646
.02000	.14080	8.43497	430.00609
.03000	.27324	12.44621	319.20894
.04000	.43286	15.39590	226.63883
.05000	.61127	17.46307	151.07080
.06000	.80171	18.81516	91.52560
.07000	.99900	19.61037	47.24209
.08000	1.19944	19.99978	17.65641
.09000	1.40079	20.12931	2.38667
.10000	1.60223	20.14148	1.22266

B. Full Size Basement--70x144x8 ft--Entrance, 80 ft^2

5 psi Flat, 156 lb. cylinder, 15 3/4 in. dia
x 22 in. high

Time,sec	Distance,ft	Velocity, ft/sec	Acceleration,ft/sec^2
.10000	.43790	3.01740	54.46407
.20000	1.36619	8.18815	43.79302
.30000	2.68507	12.32662	34.48763
.40000	4.30787	15.56675	26.44726
.50000	6.16012	18.03283	19.58738
.60000	8.17882	19.84108	13.83752
.70000	10.31177	21.10097	9.13980
.80000	12.51704	21.91649	5.44756
.90000	14.76257	22.38721	2.72442
1.00000	17.02586	22.60930	.94350
1.10000	19.29373	22.67650	.08684

C. Full Size Basement--70x144x8 ft--Entrance, 80 ft/sec

5 psi 1-MT 156 lb. cylinder, 15 3/4 in. dia x 22 in. high

Time,sec	Distance,ft	Velocity, ft/sec	Acceleration,ft/sec^2
.05000	.13994	.00000	55.97806
.10000	.39673	2.79890	46.73701
.15000	.74958	5.13575	38.42488
.20000	1.17994	7.05699	31.00341
.25000	1.67139	8.60716	24.43891
.30000	2.20960	9.82911	18.70190
.35000	2.78223	10.76421	13.76683
.40000	3.37889	11.45255	9.61184
.45000	3.99109	11.93314	6.21856
.50000	4.61222	12.24407	3.57191
.55000	5.23751	12.42266	1.66001
.60000	5.86398	12.50566	.47400
.65000	6.49047	12.52936	.00801

Table VIII-Continued

D. Full Size Basement--70x144x8 ft

5 psi Flat 170 lb cylinder, 1.28 ft dia. x 1.83 ft.high

Time,sec	Distance, ft	Velocity, ft/sec	Acceleration,ft/sec
.10000	.38960	2.68334	48.50786
.20000	1.21659	7.29191	39.12192
.30000	2.39302	10.99161	30.90402
.40000	3.84218	13.89723	23.77636
.50000	5.49797	16.11606	17.67310
.60000	7.30423	17.74912	12.53906
.70000	9.21426	18.89212	8.32859
.80000	11.19042	19.63644	5.00470
.90000	13.20376	20.06996	2.53838
1.00000	15.23382	20.27787	.90804
1.10000	17.26840	20.34335	.09913

E. Full Size Basement--70x144x8 ft

5 psi Flat 170 cylinder, 1.28ft.dia x 1.83ft. high

Time,sec	Distance,ft	Velocity,ft/sec	Acceleration,ft/sec
.10000	.35290	2.48855	41.61791
.15000	.66704	4.56945	34.26884
.20000	1.05042	6.28289	27.69416
.25000	1.48847	7.66760	21.86757
.30000	1.96843	8.76098	16.76599
.35000	2.47932	9.59928	12.36934
.40000	3.01186	10.21774	8.66040
.45000	3.55846	10.65076	5.62464
.50000	4.11318	10.93200	3.25010
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.60000	5.23140	11.17087	.44924
.65000	5.79109	11.19333	.01113

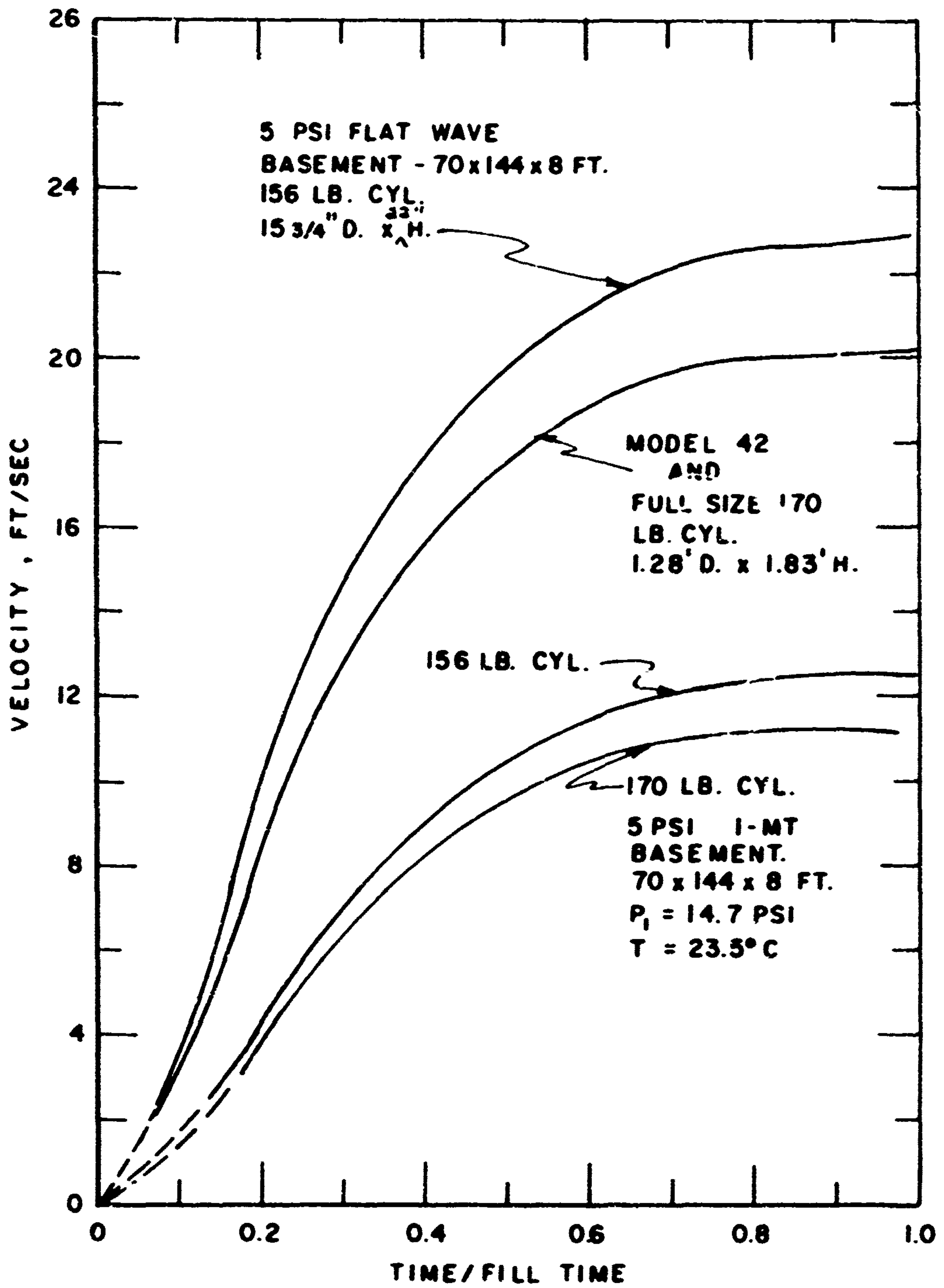

Figure 27. Comparison of Predicted Cylinder Motion-Scale Model with Full Size

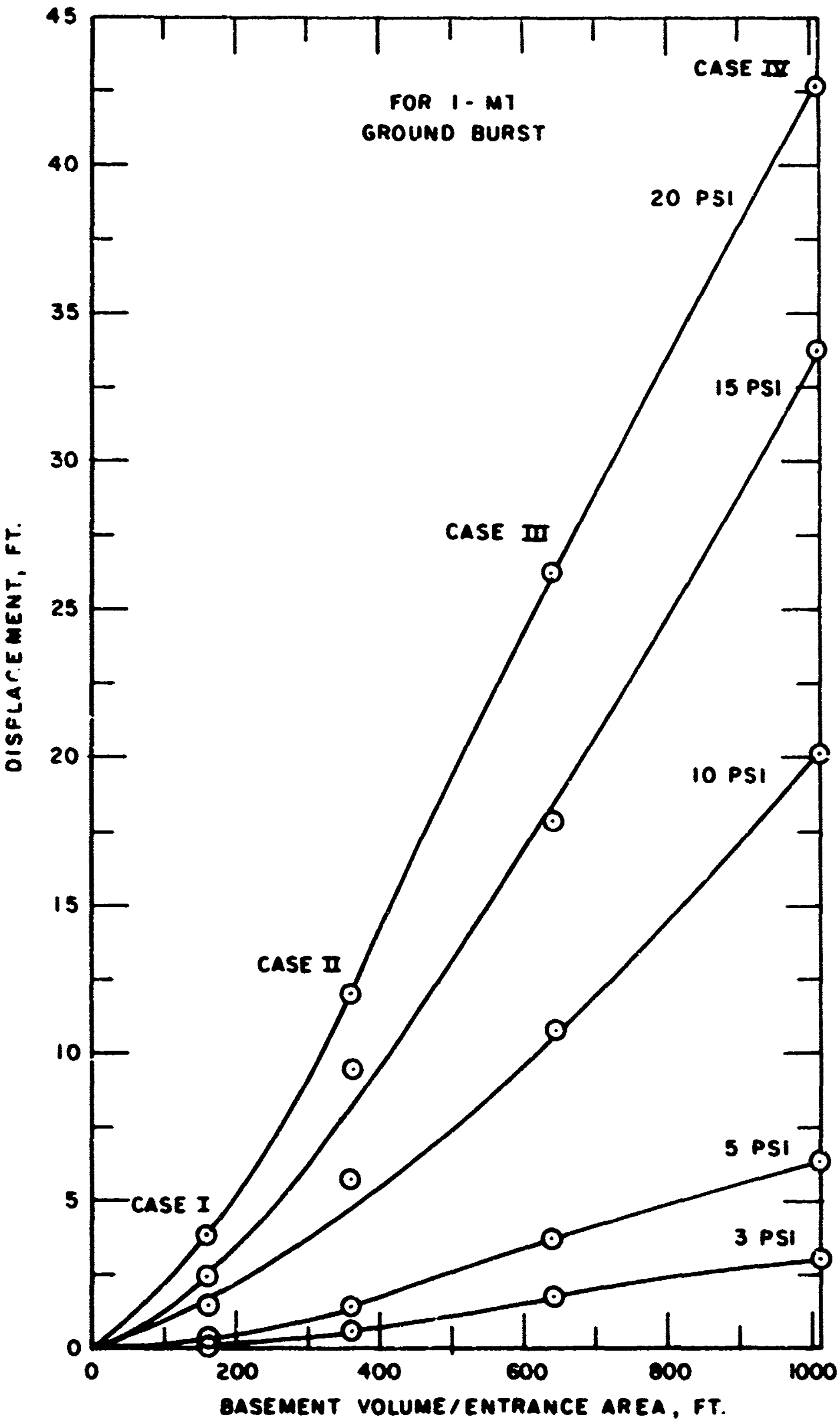

Figure 28. Displacement of 156 lb. Cylinder as a Function of Basement Volume to Entrance Area Ratio

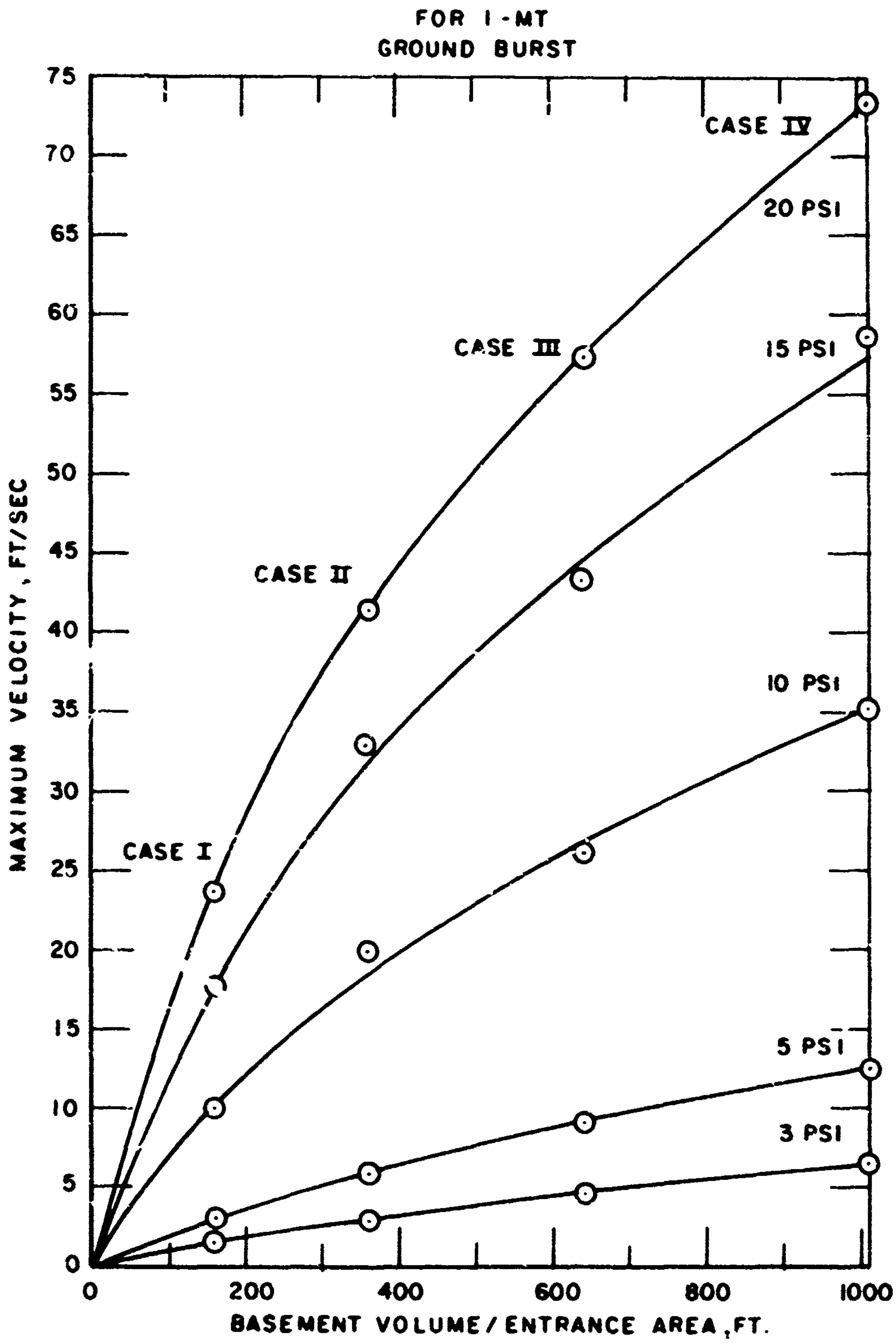

Figure 29. Velocity of 156 lb. Cylinder as a Function of Basement Volume to Entrance Area Ratio

ACKNOWLEDGEMENTS

The author wishes to thank Messrs. W. Matthews and K. Holbrook for the experimental work performed at the BRL 5.5 foot Shock Tube, and also to thank Messrs. V. Kucher and J. Harrison for the computer runs with the RIPPLE Code.

REFERENCES

1. George A. Coulter, "Blast Loading in Existing Structures - Basement Models", Ballistic Research Laboratories Memorandum Report No. 2208, August 1972.

2. "RIPPLE - A Two-Dimensional Eulerion Computer Program for Calculating Compressible Flow and Detonation Problems," Prepared for Ballistic Research Laboratories under Contract No. DA 04495 AMC 148 (x) with General Dynamics, General Atomic Division.

3. Joseph F. Melichar "The Propagation of Blast Waves into Chambers", Ballistic Research Laboratories Memorandum Report No. 1920, March 1968.

4. H. L. Murphy, "Feasibility Study of Slanting for Combined Nuclear Weapons Effects (revised) Volume 2: Appendices" Stanford Research Institute, Menlo Park, California 94025, SRI Technical Report July 1971.

5. George A. Coulter and William T. Matthews, "Coefficients of Drag Measured with a Shock Tube Force Balance", Ballistic Research Laboratories Technical Note No. 1155, August 1957.

6. S. F. Hoerner, "Fluid-Dynamic Drag", 148 Busteed Drive, Midland Park, New Jersey 07432, Published by author. 1965.

7. H. L. Brode "A Review of Nuclear Explosion Phenomena Pertinent to Protective Construction", Rand Document No. R-425-PR ECD-AD 601139, Rand Corp., Los Angeles, California, May 1964.

APPENDIX A

SUMMARY OF SHOTS

Table A-I. Summary of Shots-Model 40

Shot	Ps, psi	Position of Objects	Motion of Objects	Remarks
569	5.2	Row 1	Cylinder C moved towards right rear by 5.9 ms. velocity of 3-4 ft/sec to rear reached with a rotation of 2-5 rotations/sec. Cylinders A and B moved slightly towards entrance.	P_1 = 14.5 psi T_1 = 21.7°C Time zero is shock arrival at doorway. All velocities are in direction noted.
570	10.2	Row 1	Cylinder C moved at 4.8 ms. Cylinder B moved at 29 ms to right, fell down. C reached velocity of 11-15 ft/sec to rear with 10-15 rotations/sec. Cylinder A showed little motion.	P_1 = 14.6 psi T_1 = 21.0°C
574	20.3	Row 1	Cylinder C moved at 3.1 ms, hit upper left rear corner away from entrance. Reached a velocity of 36 ft/sec and a rotation of about 36 rotations/sec. Cylinder B reached velocity to rear of 4-8 ft/sec and 4-7 rotations/sec. Cylinder A slid to left front toward stairs.	P_1 = 14.7 psi T_1 = 21.6°C
578	5.3	Row 2	Cylinder C moved to right by 10.2 ms, tipped away from stairway and was never airborne. Velocity after 33ms was 1-2 ft/sec. Cylinders A and B showed slight motion.	P_1 = 14.8 psi T_1 = 21.2°C

Table A-I Summary of Shots-Model 40 (Continued)

Shot	Ps, psi	Position of Objects	Motion of Objects	Remarks
571	10.2	Row 2	Cylinder C moved after 3.8 ms. It was airborne at 9.5 ms with a rotation of 0.5 rotation/sec. Velocity was about 5 ft/sec after 41.3 ms. Cylinder B moved at 41.5 ms, tilted toward stairway. Cylinder A slid to left of stairs, away from doorway 1. A did not fall.	P_1 = 14.7 psi T_1 = 20.4°C
575	20.2	Row 2	Cylinder C moved towards left rear of model. It moved at 2.2 ms, gained a velocity of 11.3 ft/sec at 6.9 ms, 22.3 ft/sec at 20.9 ms, and hit rear window at 71.4 ms with a velocity of 30.1 ft/sec. rotation was 8-11 rotations/sec before impact at rear, then it became about .8 rotations/sec. Cylinders A and B moved at less that 2 ft/sec.	P_1 = 14.7 psi T_1 = 21.7°C
579	5.1	Row 3	Cylinder C moved at 5.9 ms. Slight velocity of less than 1 ft/sec was measured. Cylinder A slid toward stairway, did not fall. Slight motion for Cylinder B.	P_1 = 14.8 psi T_1 = 22.2°C
572	10.0	Row 3	Cylinder C moved away from stairway. Cylinders B and A moved toward stairway end. All cylinders moved 2-4 ft/sec.	P_1 = 14.7 psi T_1 = 20.9°C

Table A-I Summary of Shots-Model 40 (Continued)

Shot	Ps,psi	Position of Objects	Motion of Objects	Remarks
576	20.1	Row 3	Cylinder C moved toward left rear of model at 7.6 ms. It attained 7.9 ft/sec at 14.3 ms and 13.4 ft/sec at 257.4 ms. Rotation varied from 12-22 rotations/sec. Cylinder B simply fell over. Cylinder A moved to left front, airborne at 10.5 ms, and attained 6.4 ft/sec at 72.2 ms.	P_1 = 14.7 psi T_1 = 22.1°C
580	5.1	Row 5	All cylinders slid, not airborne and slight motion.	P_1 = 14.8 psi T_1 = 20.7°C
573	10.2	Row 5	Cylinder C moved toward rear of model at 9.8 ms and fell at 24.5 ms. Cylinder B slid slightly toward stairs, did not fall. Cylinder A rolled and slid at 3.5ft/sec toward stairs.	P_1 = 14.7 psi T_1 = 21.3°C
577	20.2	Row 5	Cylinder C moved toward center rear of model at 8.3 ms, was airborne at 28 ms, and hit rear window at 54.6 ms. Diagonal velocity was 8.9 ft/sec. Moved back toward front at 9 ft/sec. Cylinder B tumbled at 8-10 rotations/sec. Cylinder A did not fall down.	P_1 = 14.7 psi T_1 = 22.2°C

Table A-II. Summary of Shots-Model 42

Shot	Ps,psi	Position of Objects	Motion of Objects	Remarks
5-73-3	4.9	Camera 1, 2 ft-3ft lines	Cylinder 1 not seen. Cylinders 2 & 3 moved toward rear at 14-17 ft/sec after 75 msec. Cylinder 4 moved toward rear at 2-3 ft/sec after 113 msec. Cylinder 5 began to move at about 11 msec and had gone 1 ft in about 100 msec. Dust motion to front along left side at 50-60 ft/sec.	P_1=14.98 psi T_1=12.2°C
		Camera 2, 6ft-7ft lines	Cylinder 15 gained a velocity of about 7 ft/sec to rear after 132 msec. Cylinder 10 had a velocity to rear of about 7 ft/sec after 311 msec, 12.3 rot/sec cylinder 5 passed lines with 8-10ft/sec going to rear. Rotations of 17.8 rot/sec were observed. Cylinder 3 passed to rear with a velocity of 4-6 ft/sec, 7.5 rot/sec. Cylinder 12, 13 and 14 showed only slight motion. Dust was observed in clockwise motion to front on left side at about 48 ft/sec.	
		Camera 3, 9ft-10ft lines	Cylinder 16 moved toward front slightly.	
5-73-6	10.0	Camera 1, 2ft-3ft lines	Cylinder 1 was not observed. Cylinder 2 had average velocity over 1 ft of 15 ft/sec. Cylinder 3 attained about 12 ft/sec after 88 msec. Cylinder 4 showed slight motion. Cylinder 5 attained about 24 ft/sec after 67 msec.	P_1=14.9 psi T_1=12.8°C Model did not quite fill because of small pressure leaks around the light ports.

Table A-II. Summary of Shots-Model 42 (Continued)

Shot	Ps, psi	Position of Objects	Motion of Objects	Remarks
5-73-6	10.0	Camera 2, 6ft-7ft lines	Cylinder 15 moved after about 21 msec, attained a velocity to rear of 19 ft/sec after about 100 msec. Cylinder 10 was moving to rear at 25 ft/sec after 115 msec. Cylinder 5 moved to rear at 33 ft/sec after 190 msec. Cylinder 3 attained a velocity of about 13 ft/sec to rear after 300 msec. Cylinders 11, 12 and 13 fell toward front. Cylinder 16 moved past towards front at 3-4 ft/sec after 590 msec. Cylinder 2 attained an average velocity of about 43 ft/sec to rear.	
	10.0	Camera 3, 9ft-10ft lines	Cylinder D attained about 12 ft/sec to rear after 150 msec. Cylinder 15 went past towards rear at 30 ft/sec after 160 msec. Cylinder 10 went past to rear, at about 34 ft/sec after 215 msec. Cylinder 5 went past to rear at about 38 ft/sec after 240 msec. Cylinders B & C moved only slightly, Cylinder 3 moved past at about 10 ft/sec, towards rear.	
5-73-7	10.1	Camera 1, 2ft-3ft lines	Cylinder 1 was not observed. Cylinder 2 had an average velocity to rear of 13 ft/sec after 76 msec. Cylinder 3 attained about 11 ft/sec after 91 msec. Cylinder 4 moved slightly to front of model with 9.5 rot/sec. Cylinder 5 attained a velocity of about 25 ft/sec after 60 msec, but moved after about 4 msec.	P_1 = 14.9 psi T_1 = 19.4°C A slight air leak still remained.

Table A-II. Summary of Shots-Model 42 (continued)

Shot	Ps,psi	Position of Objects	Motion of Objects	Remarks
		Camera 2, 6ft-7ft lines	Cylinder 15 moved after about 22 msec and attained a velocity of about 14 ft/sec after .75 ft travel at 91.5 msec. Cylinder 10 passed 6.5 ft line at about 140 msec with a velocity of 22 ft/sec. Cylinder 5 passed at about 150 ms with a velocity of 30-40 ft/sec. Cylinder 2 passed with an average velocity to rear of about 37 ft/sec. Cylinders 11, 12 and 13 fell towards front of model. Cylinder 14 moved to rear slightly at < 1 ft/sec.	
5-73-7	10.1	Camera 3, 9ft-10ft lines	Cylinder D reached a velocity to rear of 9.5 ft/sec after 152 msec. Cylinder 15 had a velocity of 20 ft/sec after 242 msec. Cylinder 10 passed with a velocity of about 30 ft/sec after 250 msec. Cylinder 5 reached an average velocity of about 36 ft/sec from 9-10 ft lines. It crossed last line at 242 msec. Cylinder C moved slowly at about 3 ft/sec after about 300 msec. Cylinder A moved slightly to front and B fell after 178 msec.	

APPENDIX B

HIGH SPEED PHOTOGRAPHS-MODEL 40

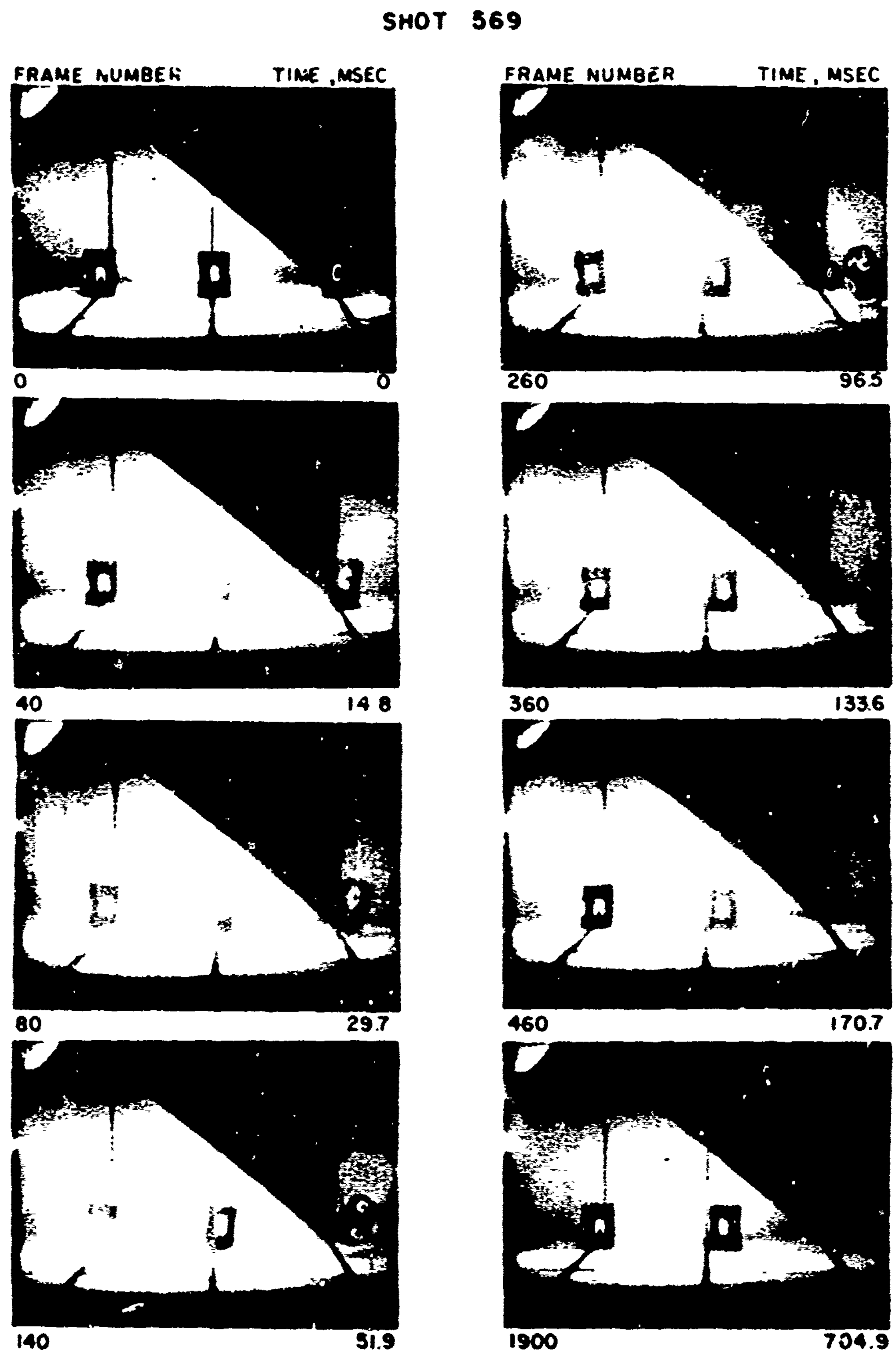

Figure B-1. End View, Cylinders on Row 1--5.2 psi

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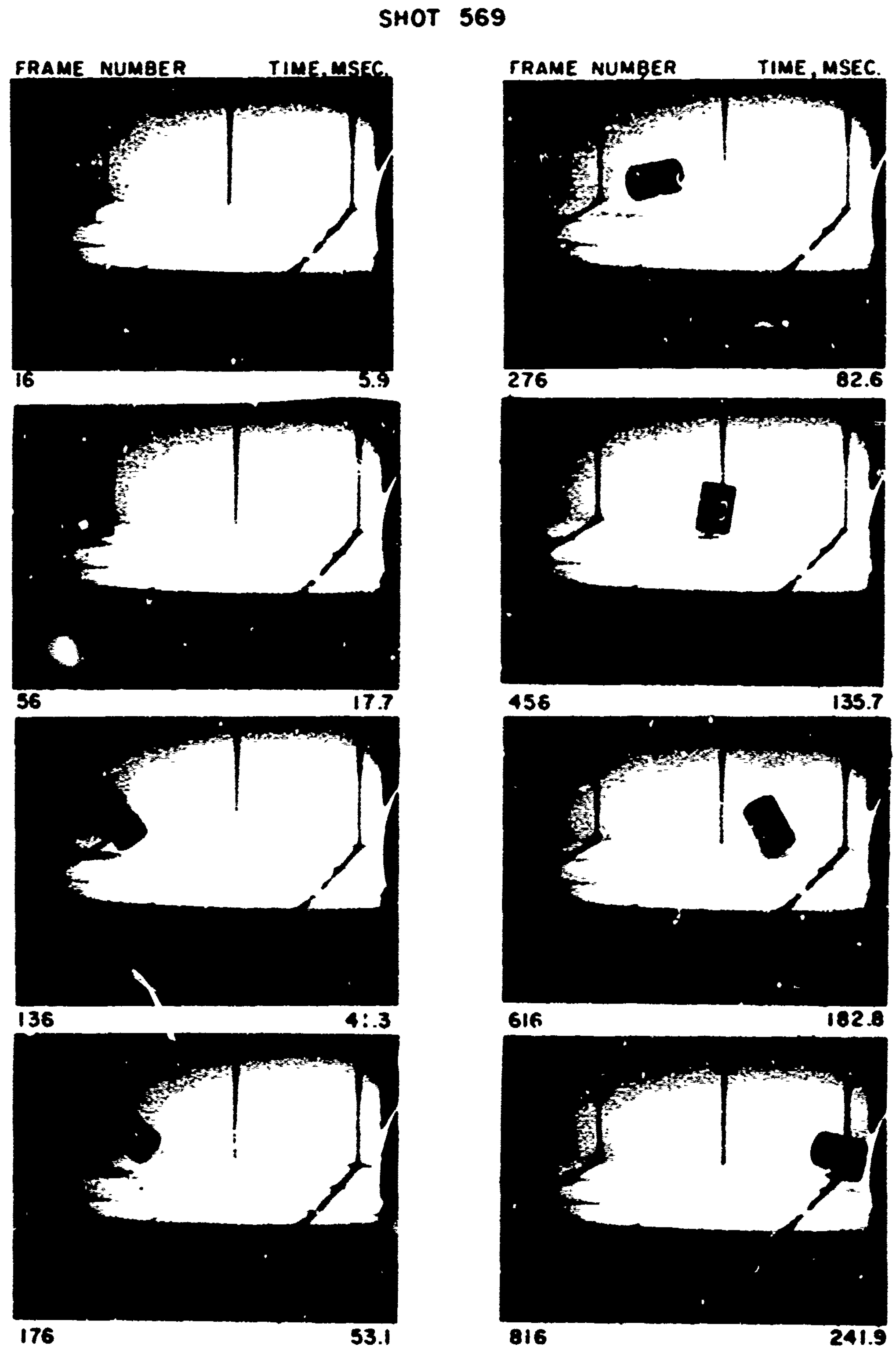


Figure B-2. Side View, Cylinders on Row 1--5.2 psi

SHOT 570

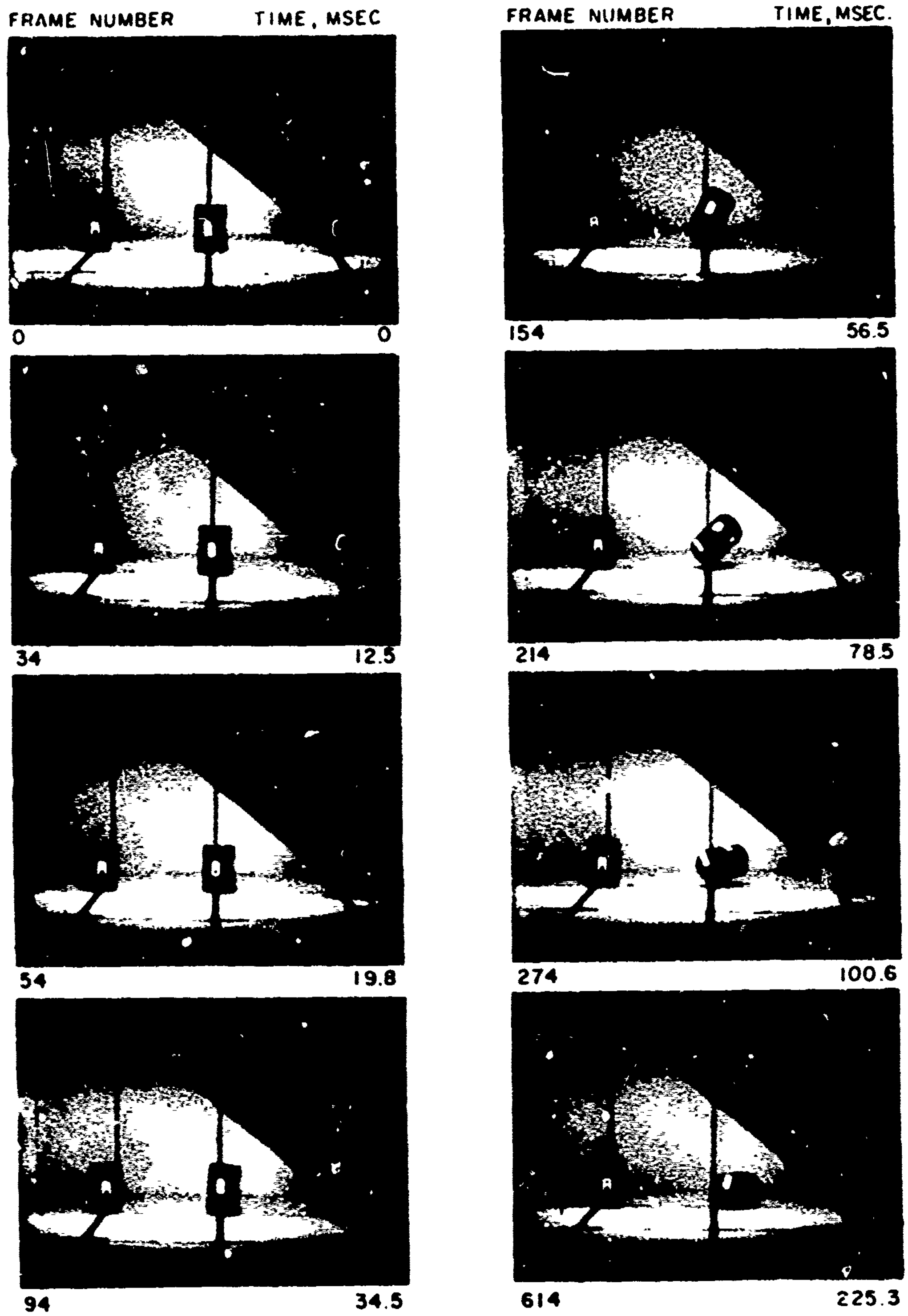


Figure B-3. End View, Cylinders on Row 1--10.2 psi

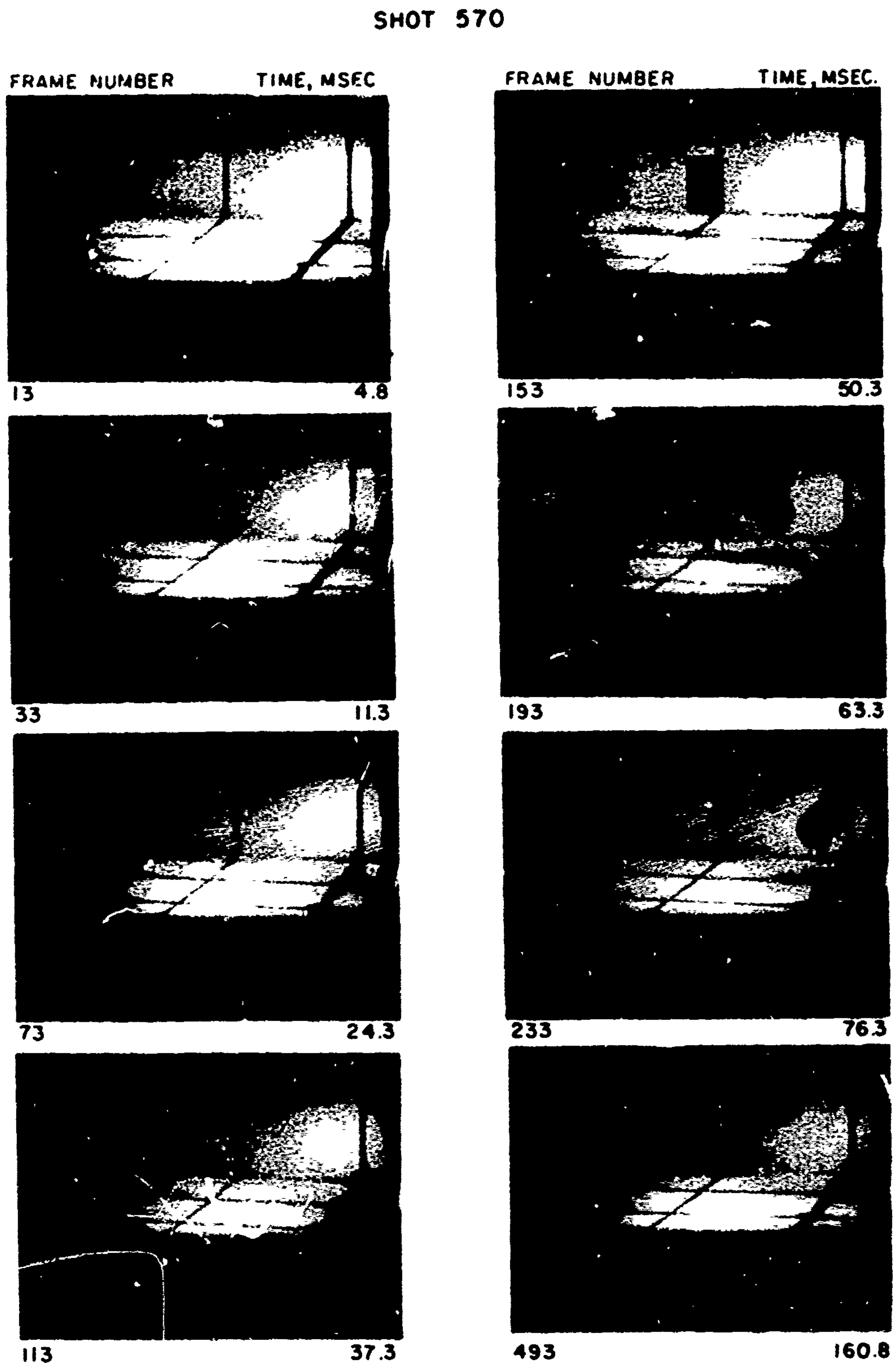


Figure B-4. Side View, Cylinders on Row 1--10.2 psi

SHOT 574

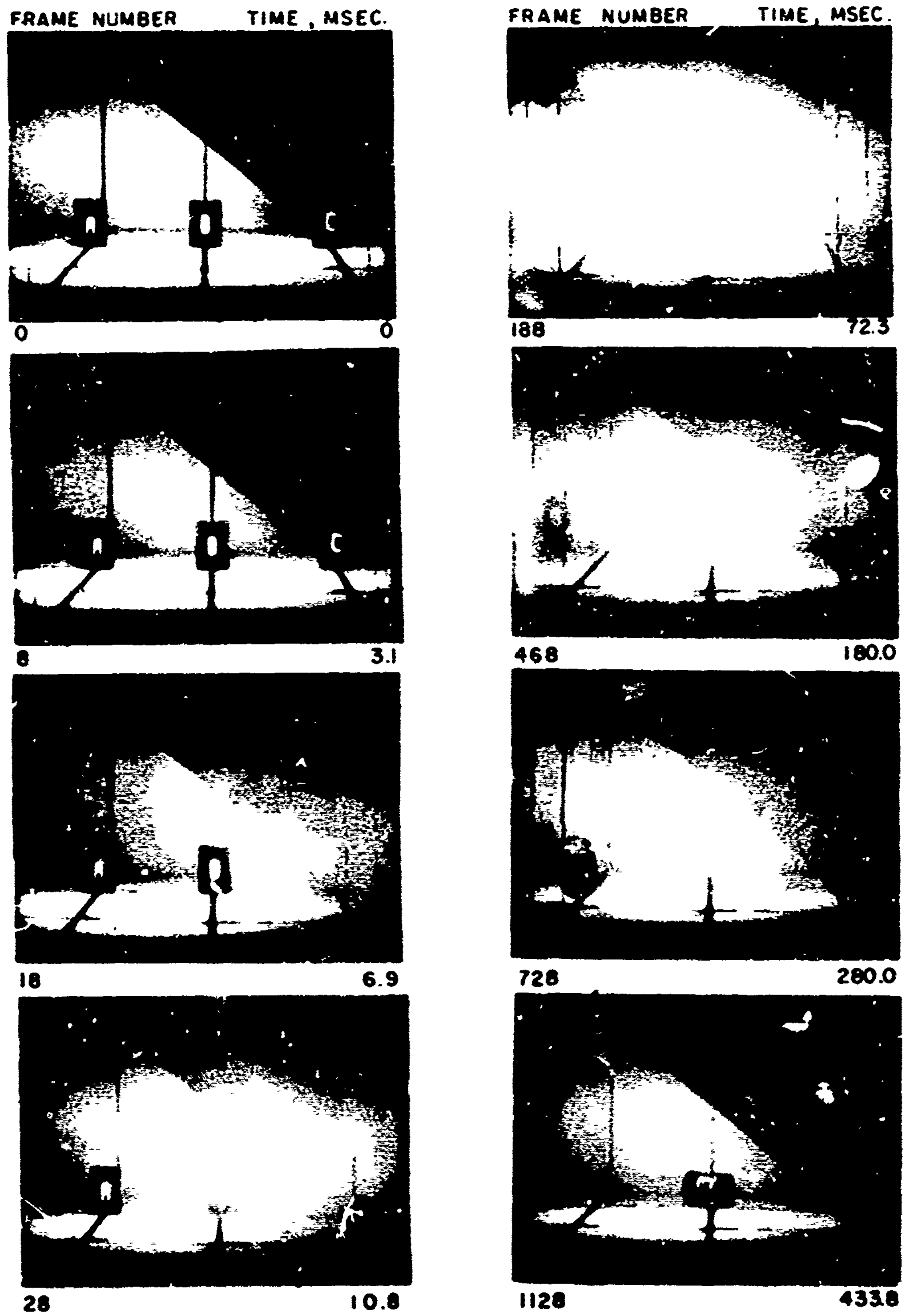


Figure B-5. End View, Cylinders on Row 1--20.3 psi

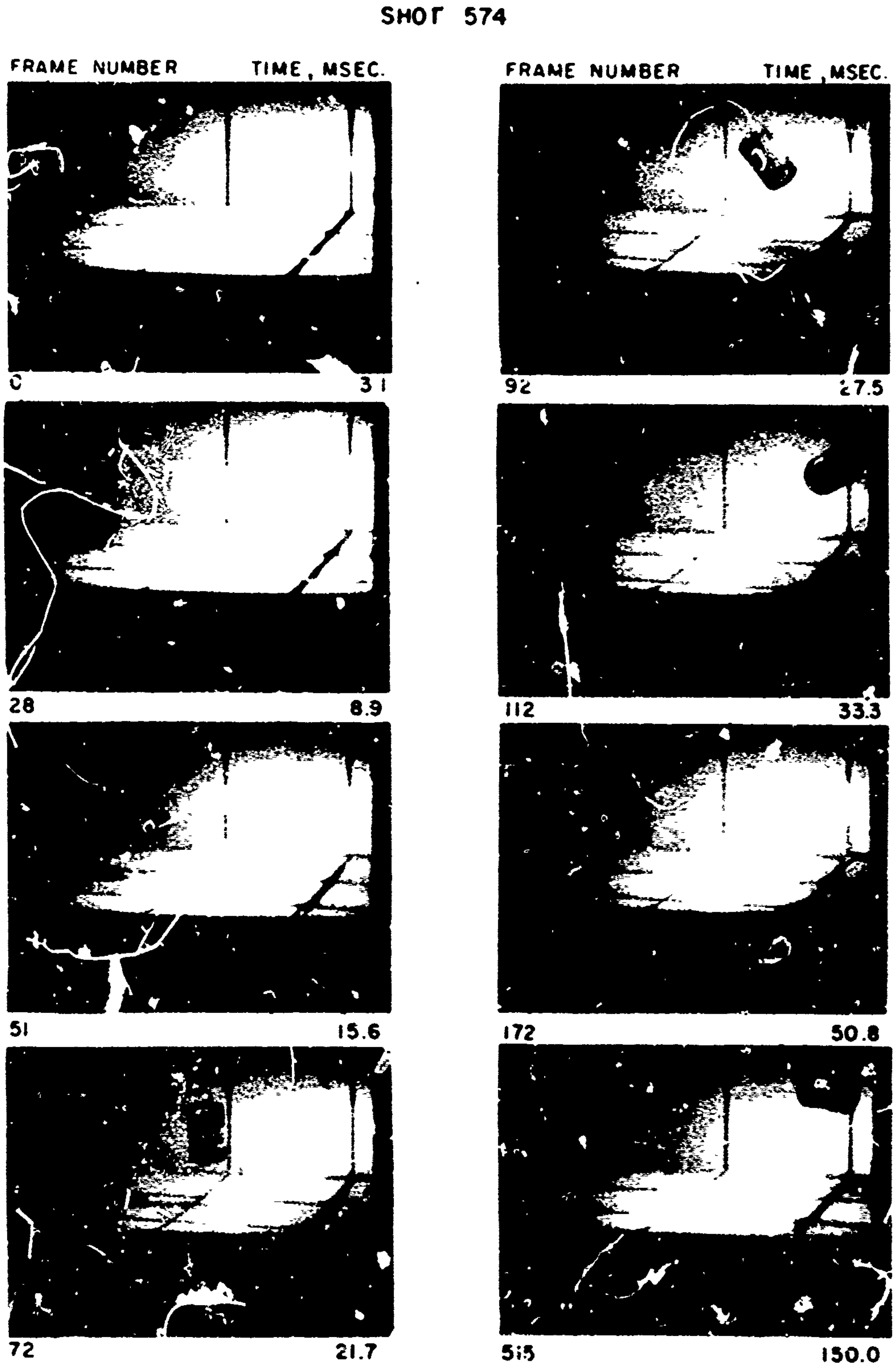


Figure B-6. Side View, Cylinders on Row 1--20.3 psi

SHOT 578

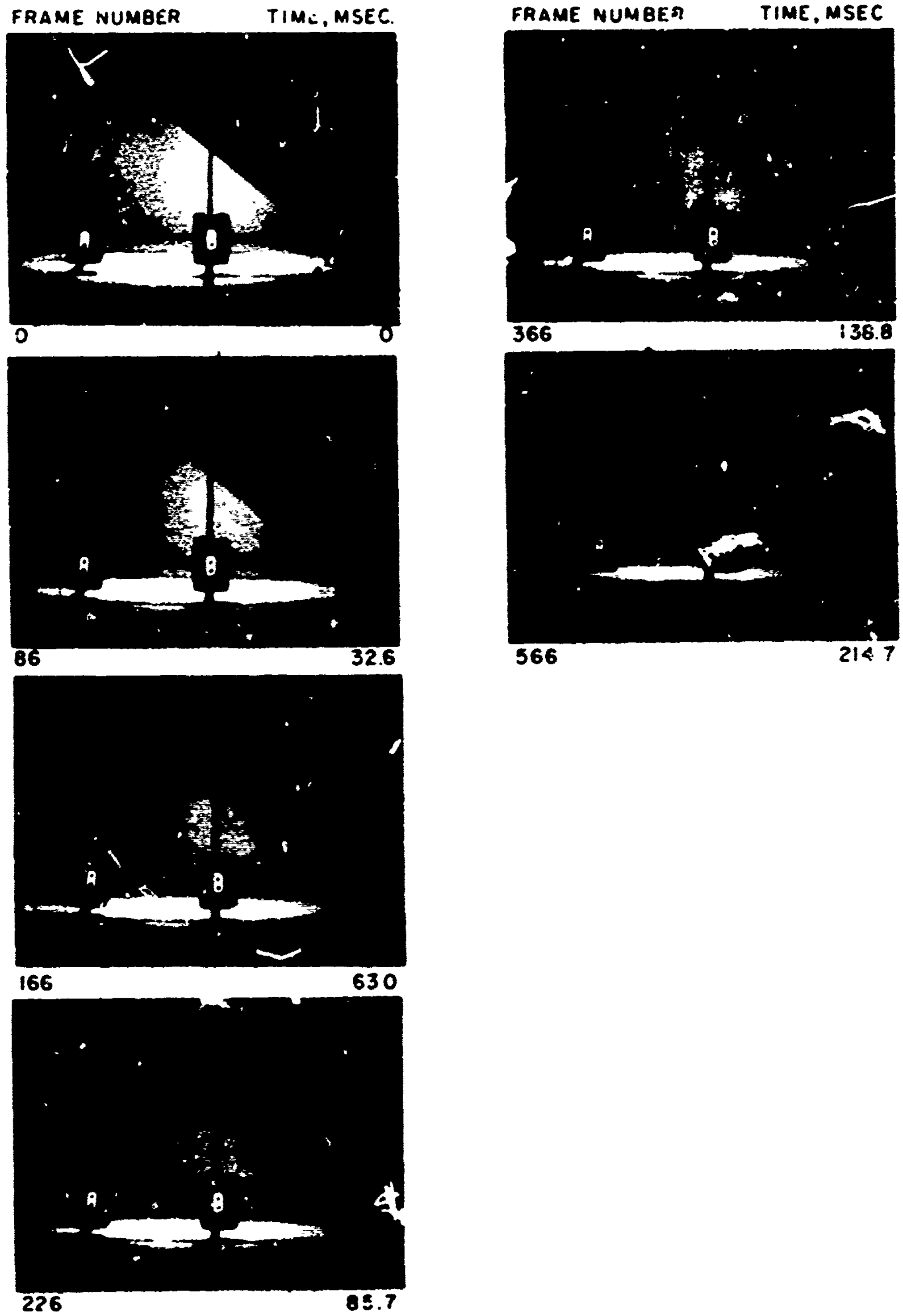


Figure B-7. End View, Cylinders on Row 2--5.3 psi

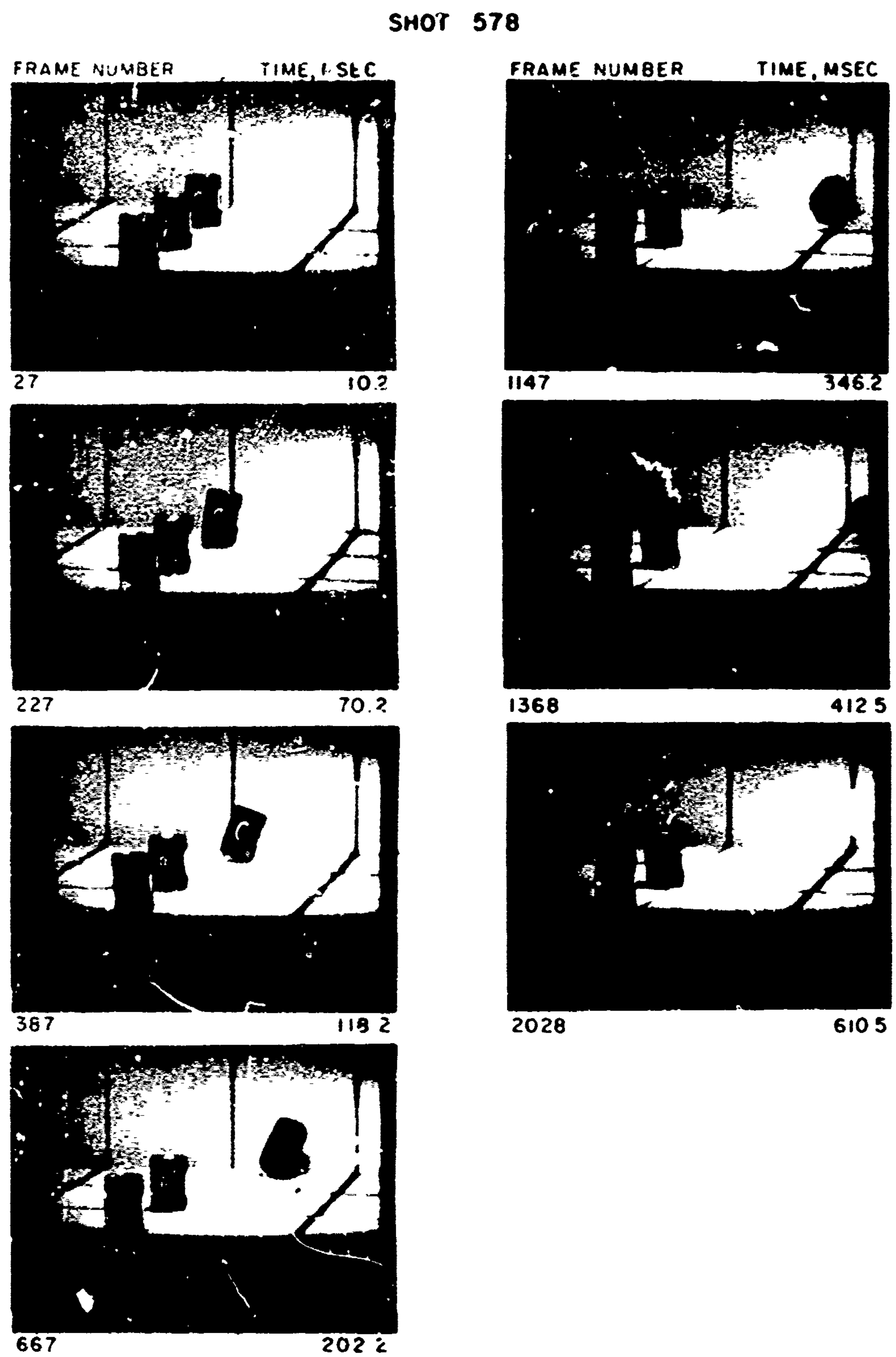


Figure B-8. Side View, Cylinders on Row 2--5.3 psi

SHOT 571

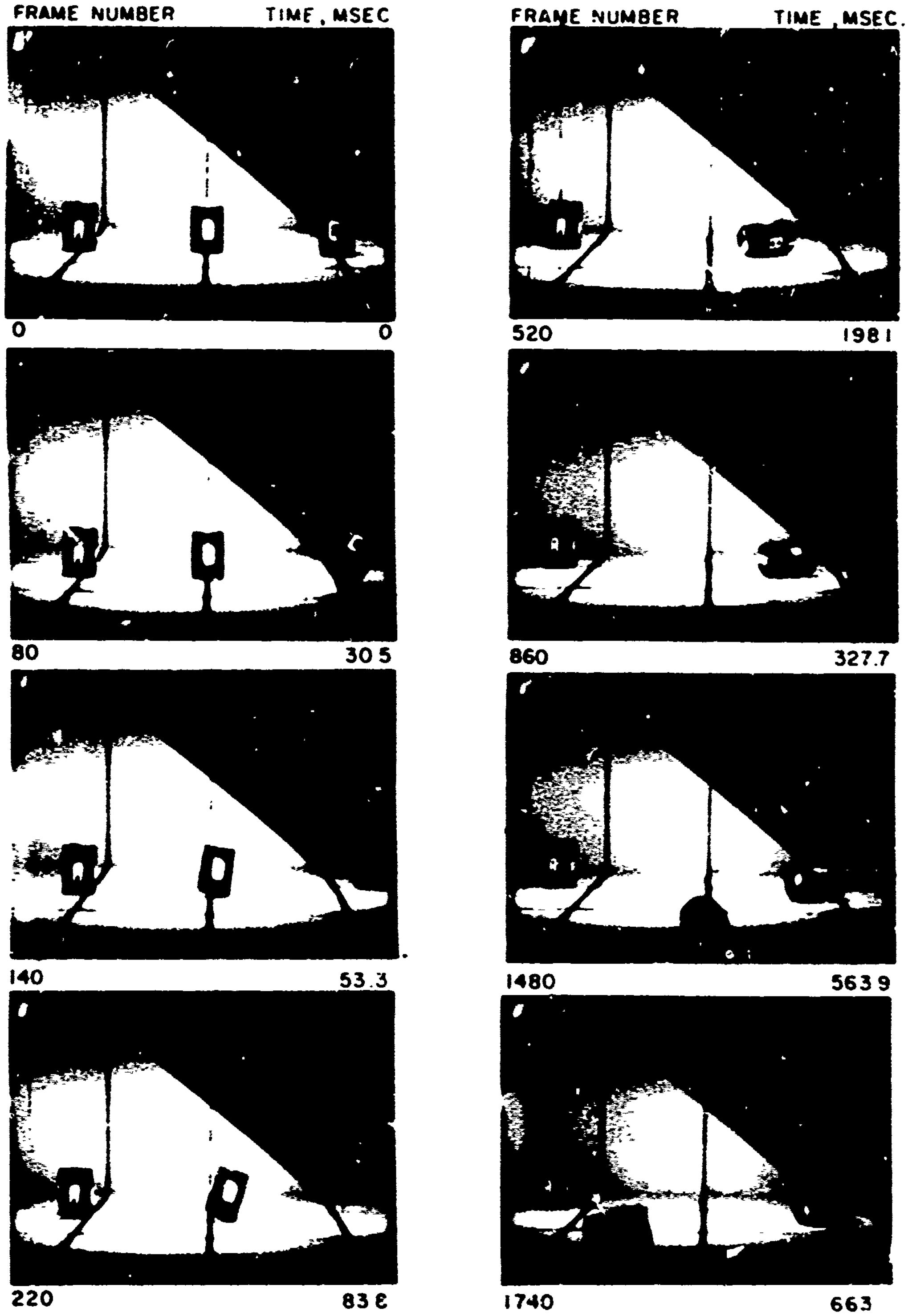


Figure 6-9. End View, Cylinders on Row 2--10.2 psi

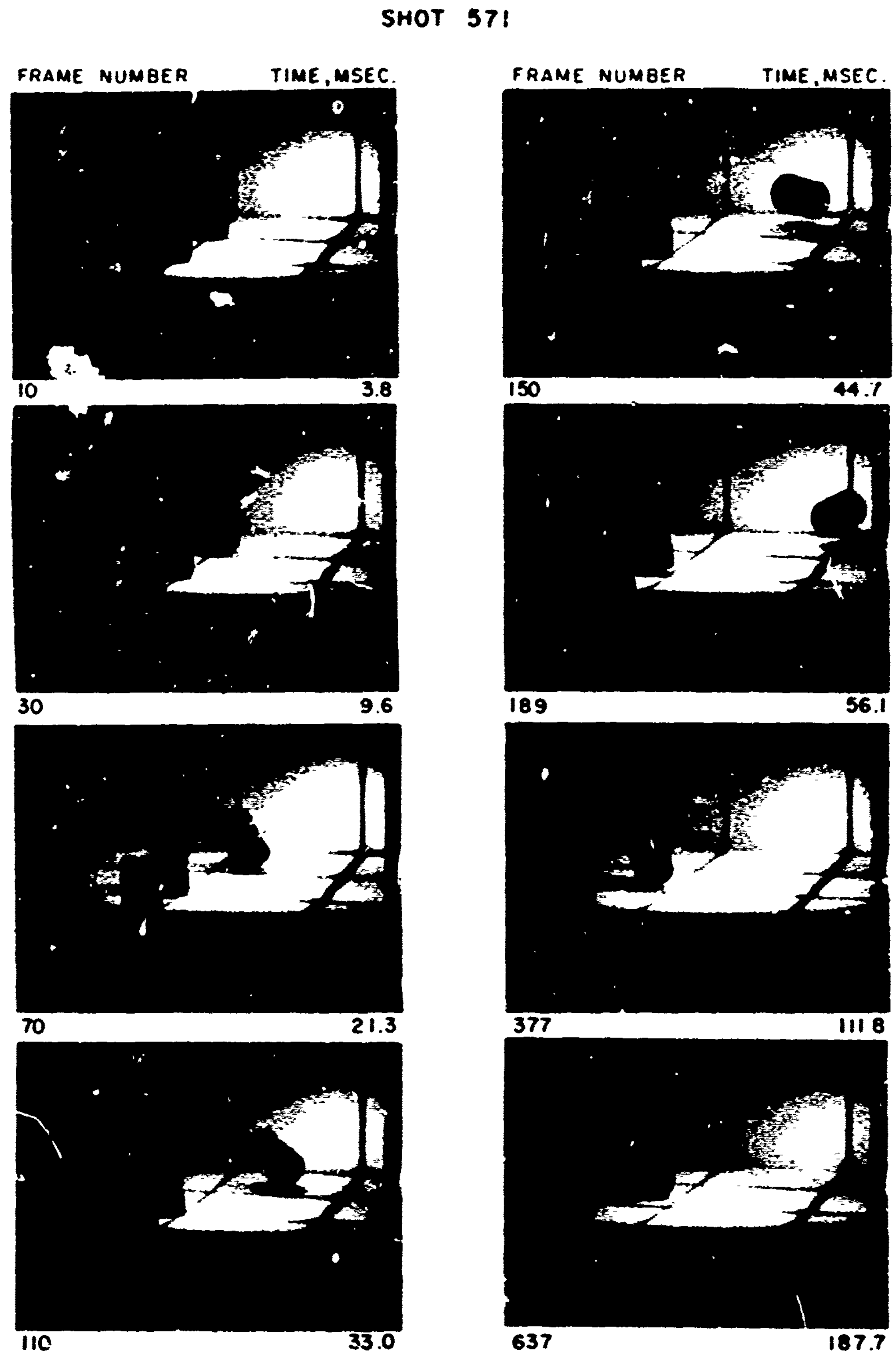


Figure B-10. Side View, Cylinders on Row 2--10.2 psi

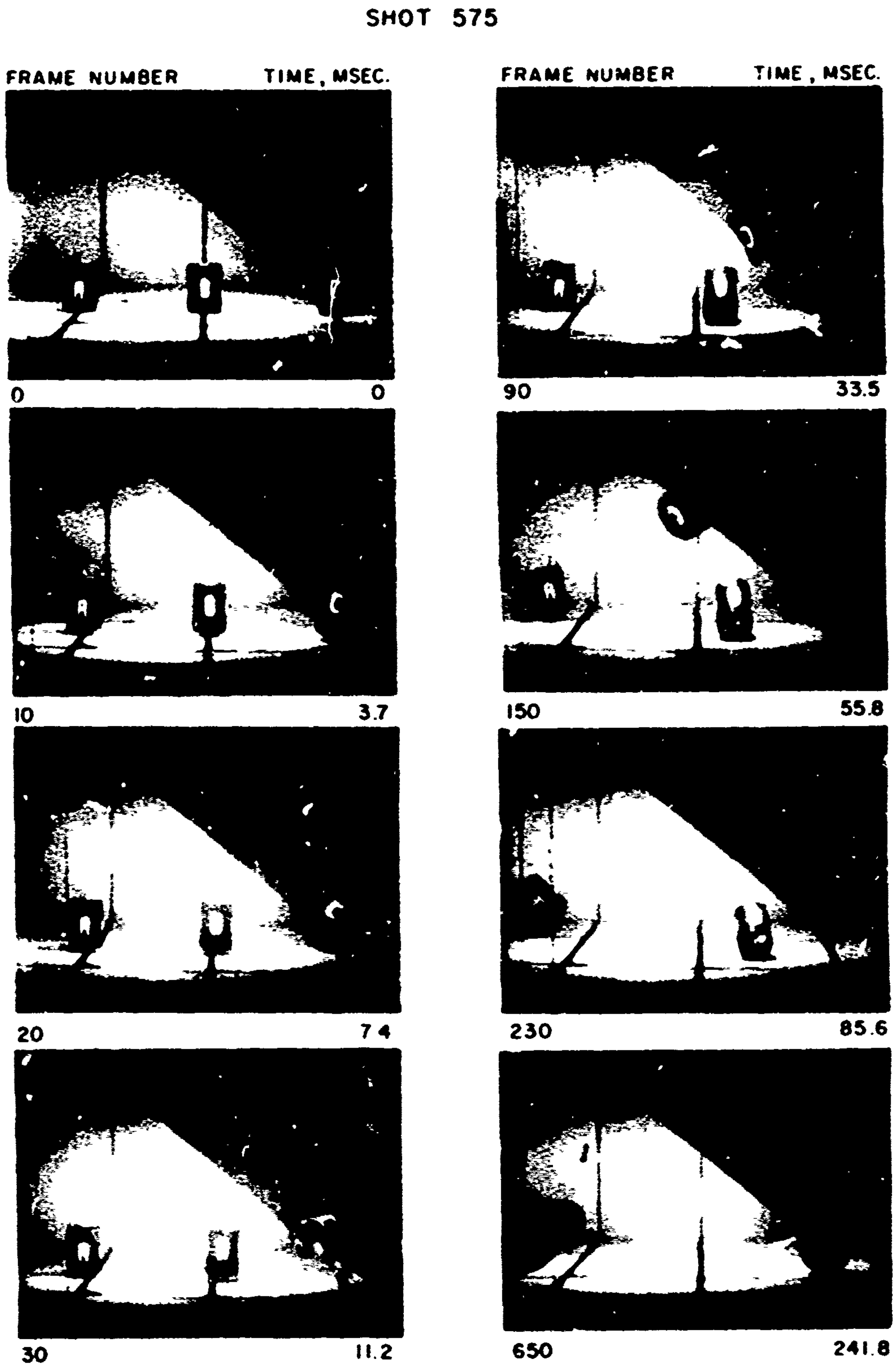


Figure B-11. End View, Cylinders on Row 2--20.2 psi

SHOT 575

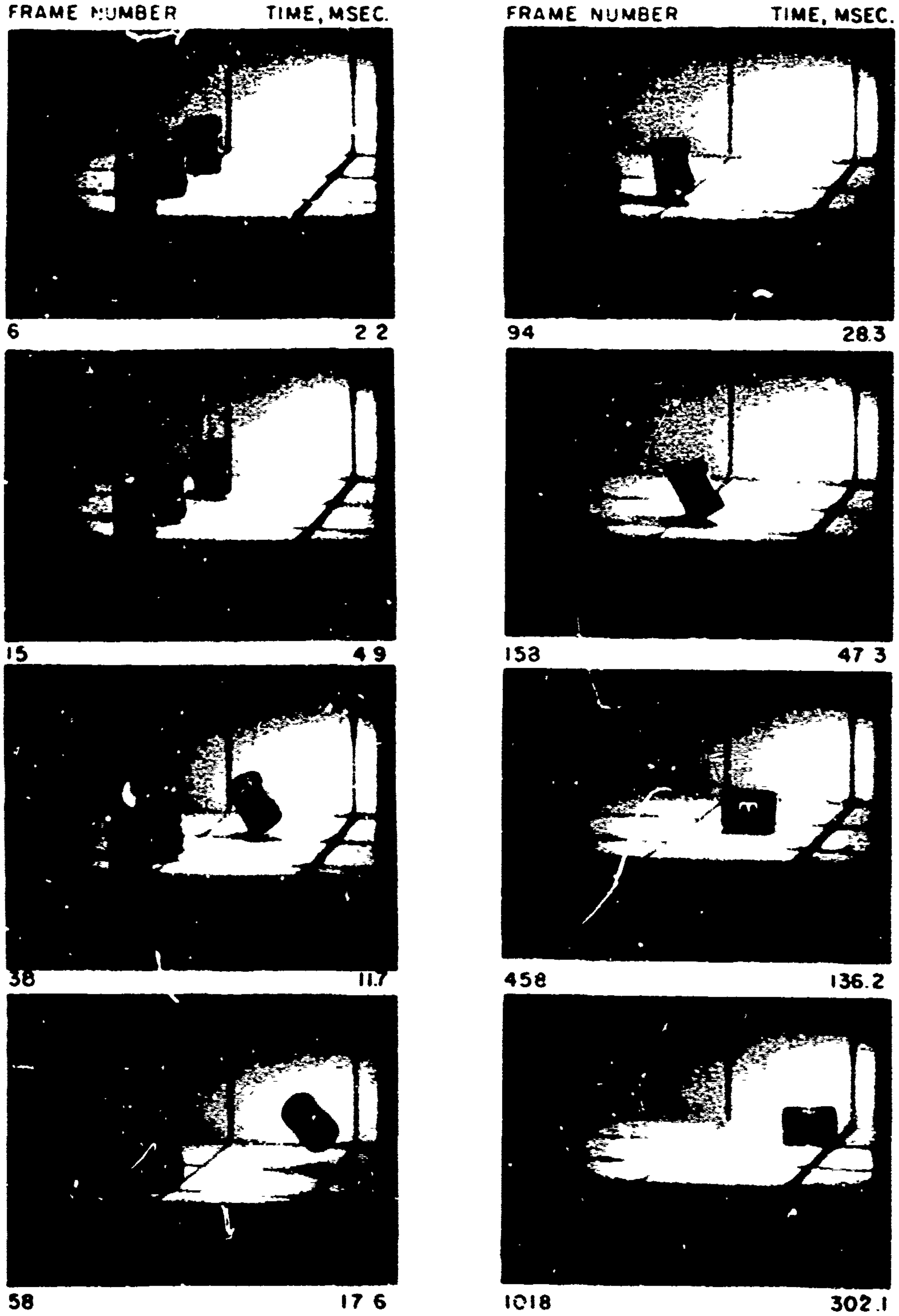


Figure B-12. Side View, Cylinders on Row 2--20.2 psi

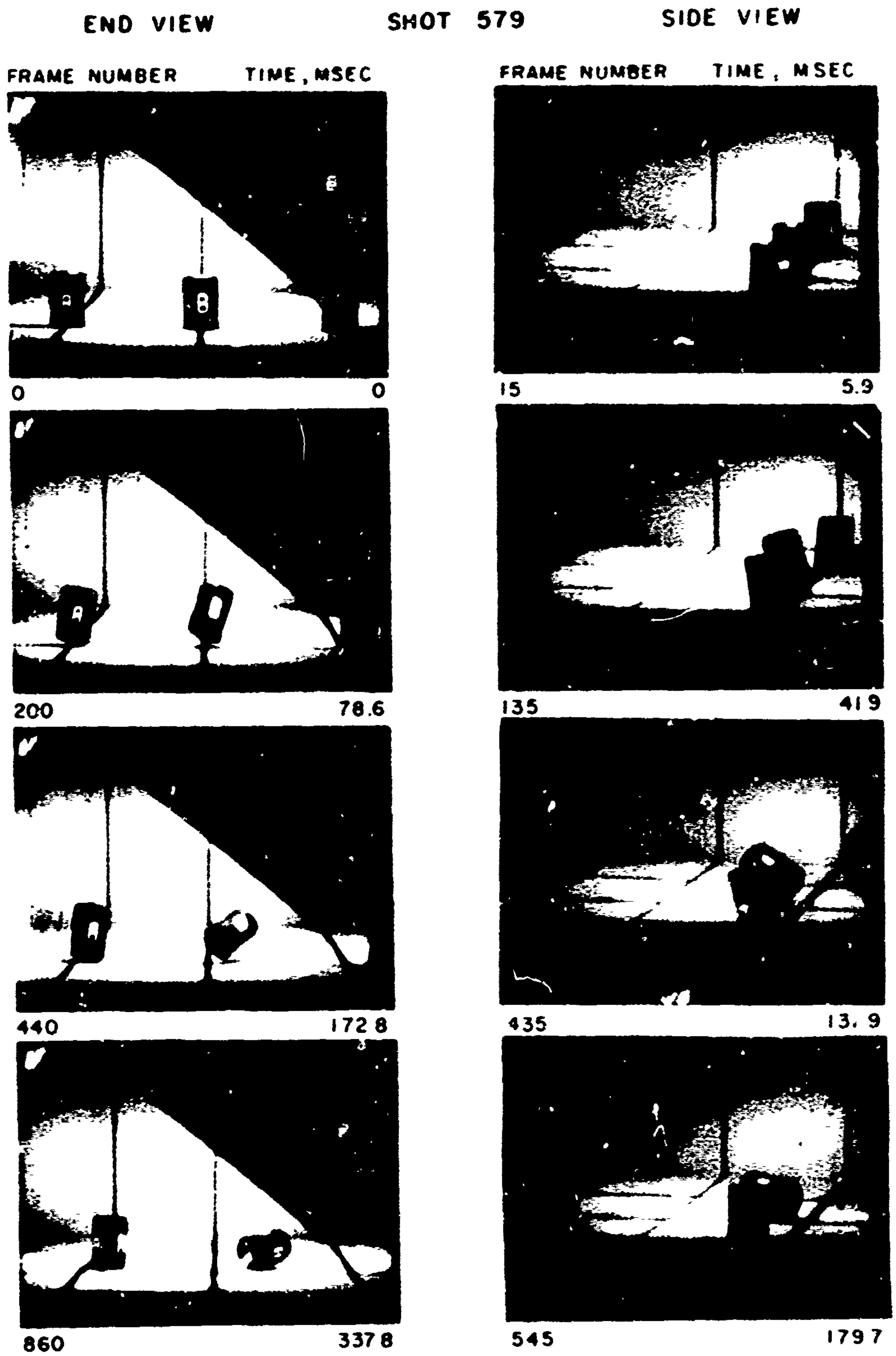


Figure B-13. End and Side Views, Cylinders on Row 3--5.1 psi

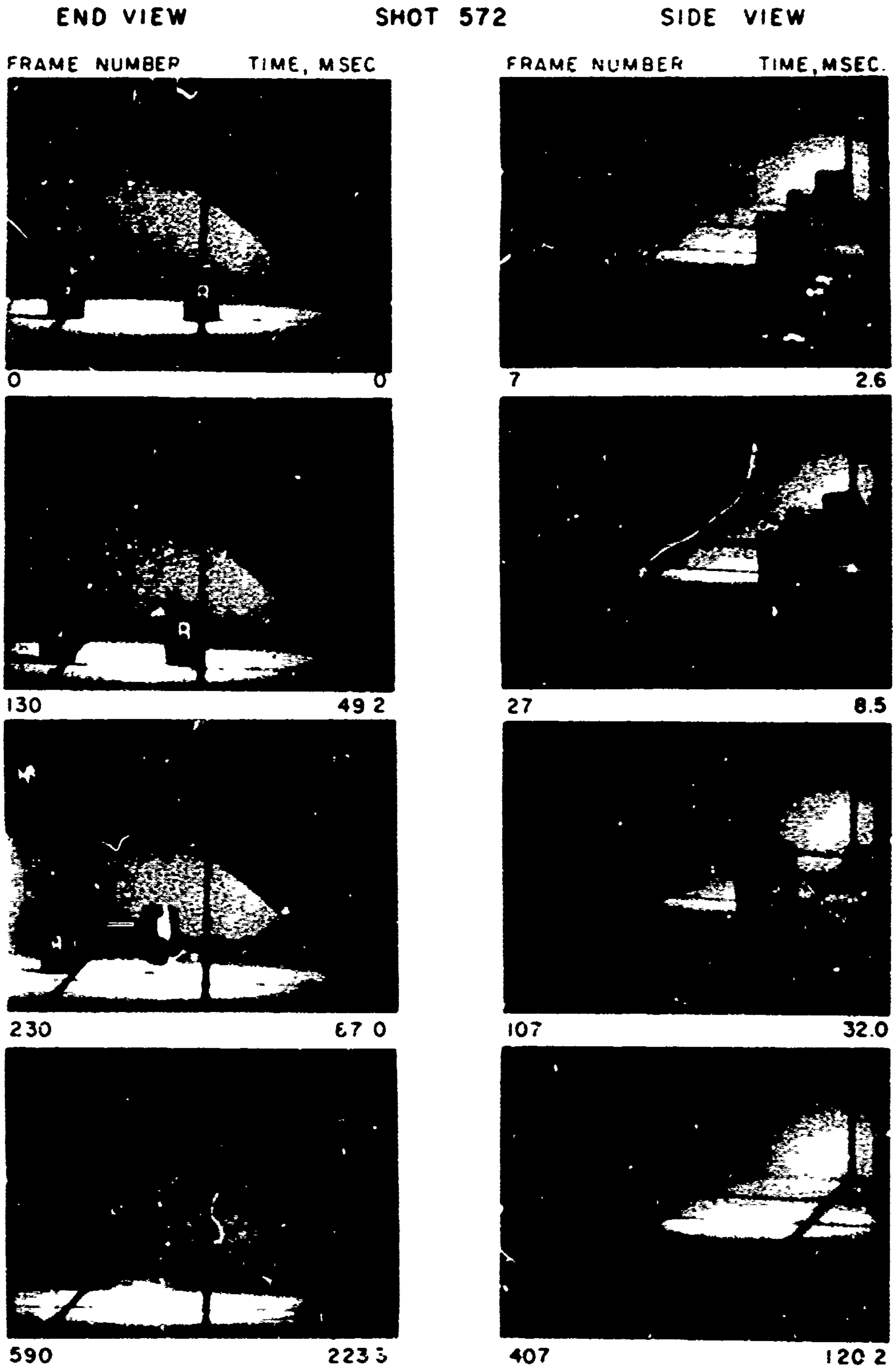
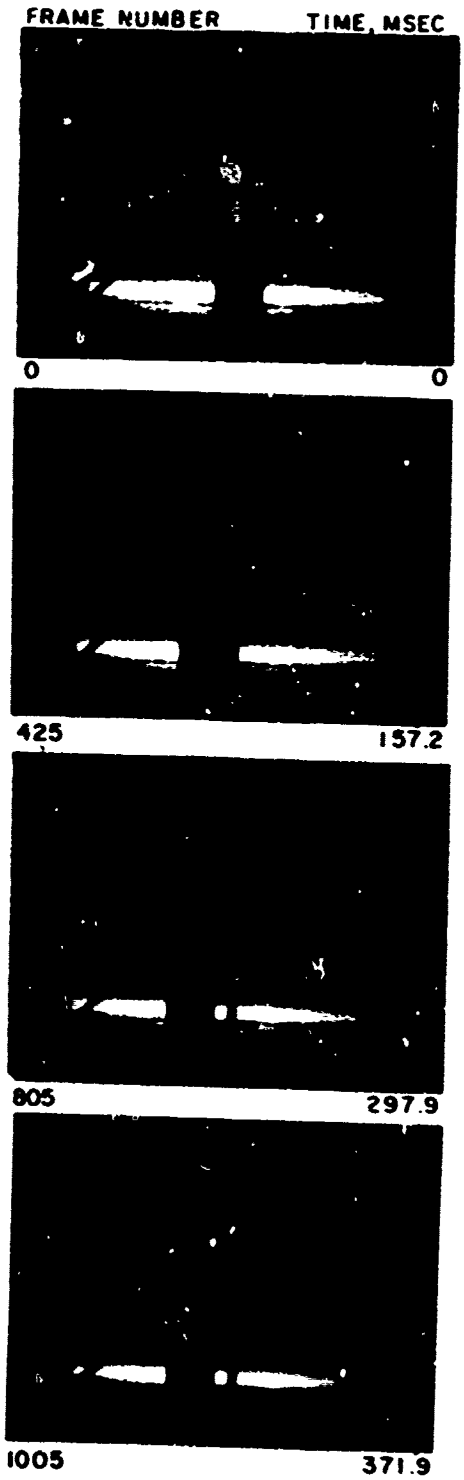


Figure B-14. End and Side Views, Cylinders on Row 3--10.0 psi

SHOT 580



NO SIDE VIEW
ON THIS SHOT

Figure B-15. End View, Cylinders on Row 5--5.1 psi

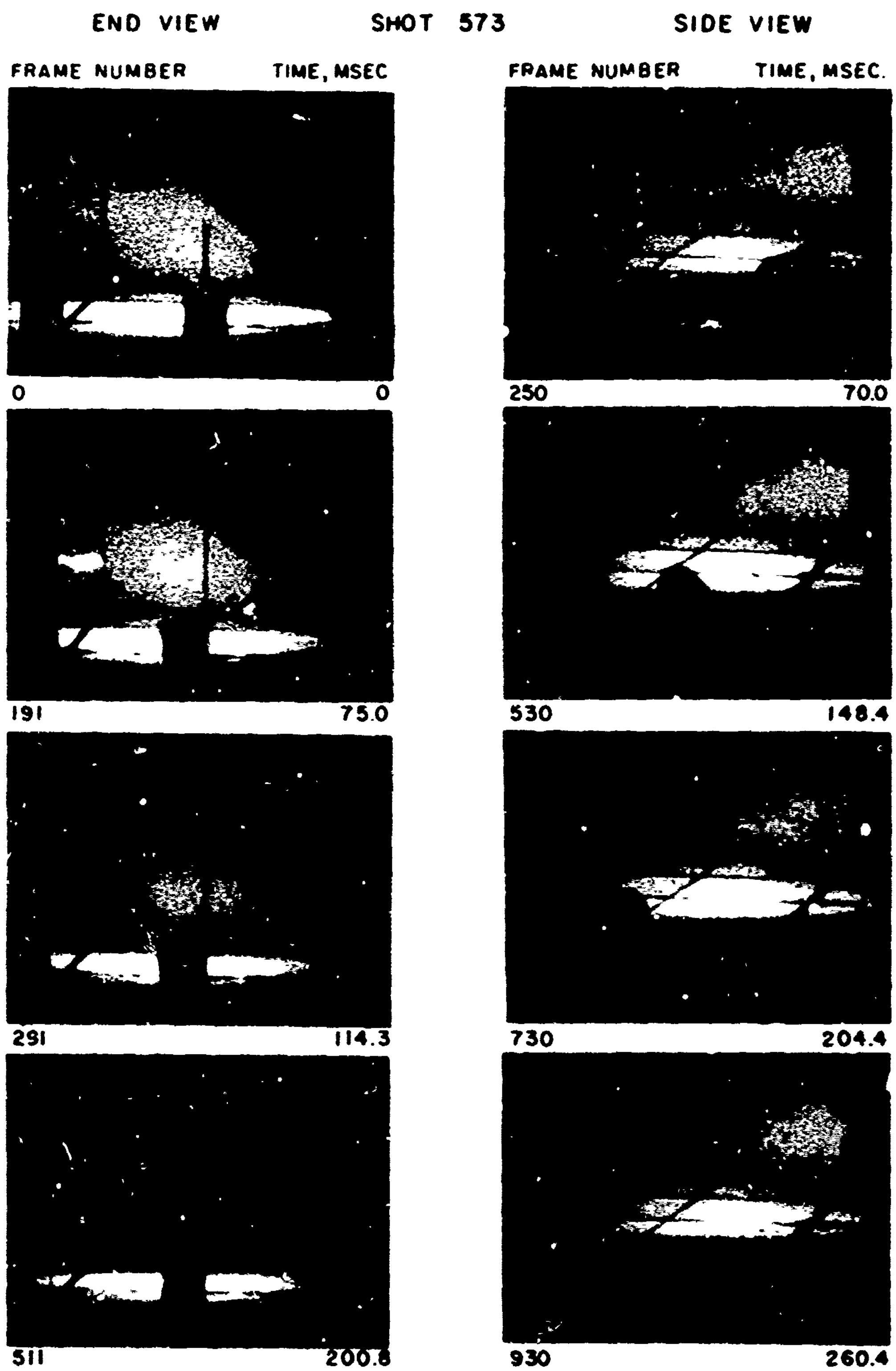


Figure B-16. End and Side Views, Cylinders on Row 5--10.2 psi

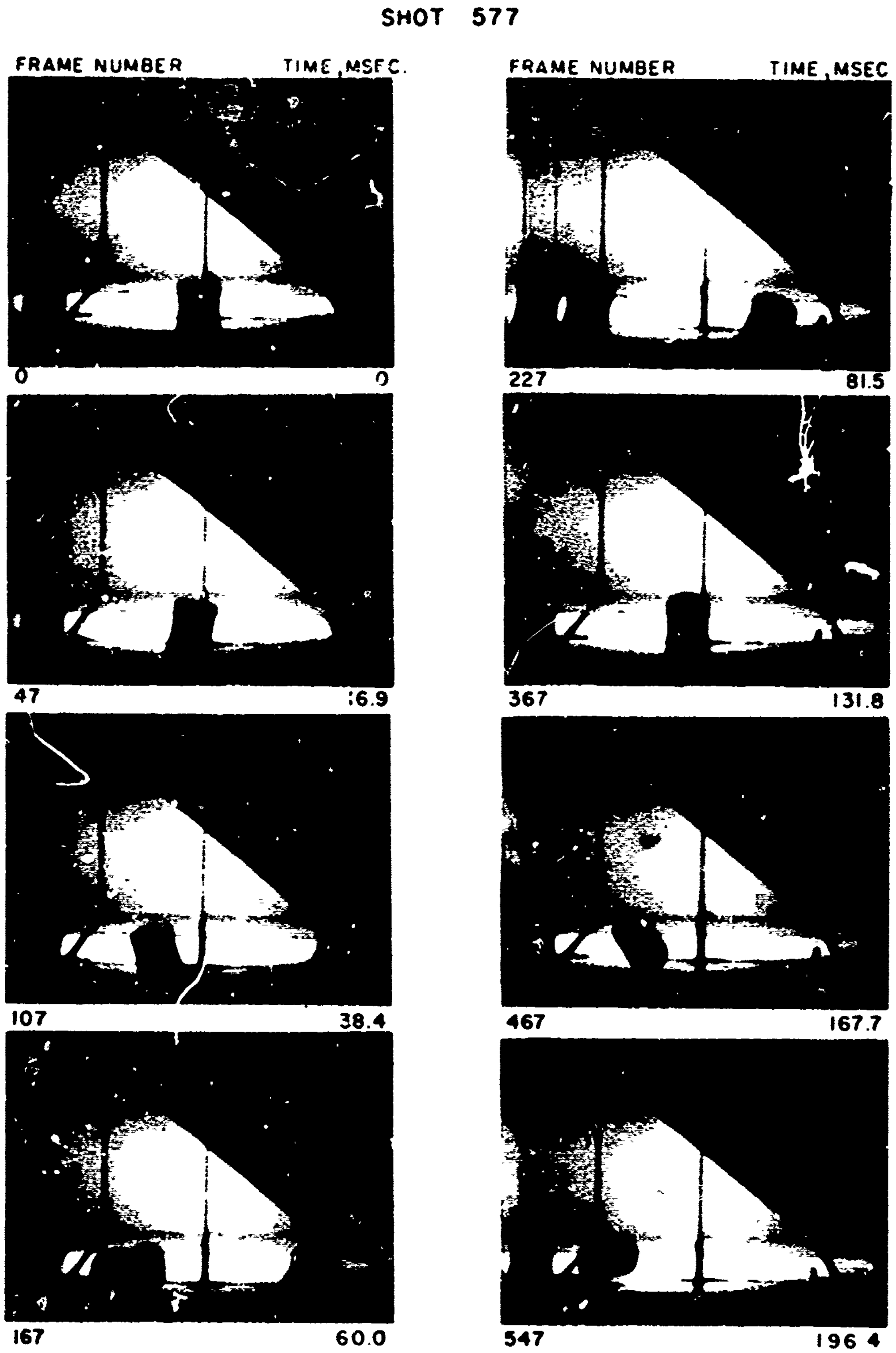


Figure B-17. End View, Cylinders on Row 5--20.2 psi

SHOT 577

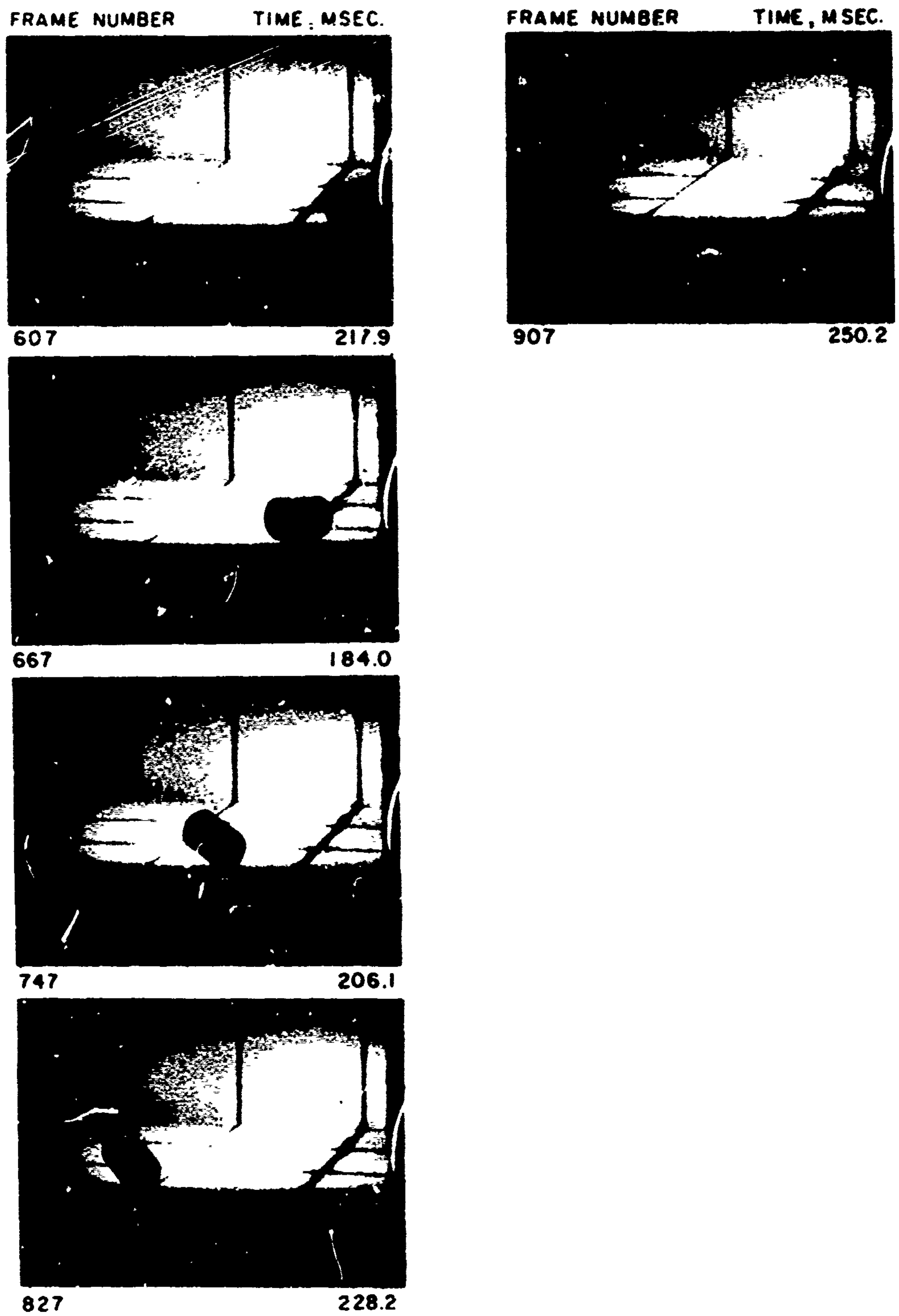


Figure B-18. Side View, Cylinders on Row 5--20.2 psi

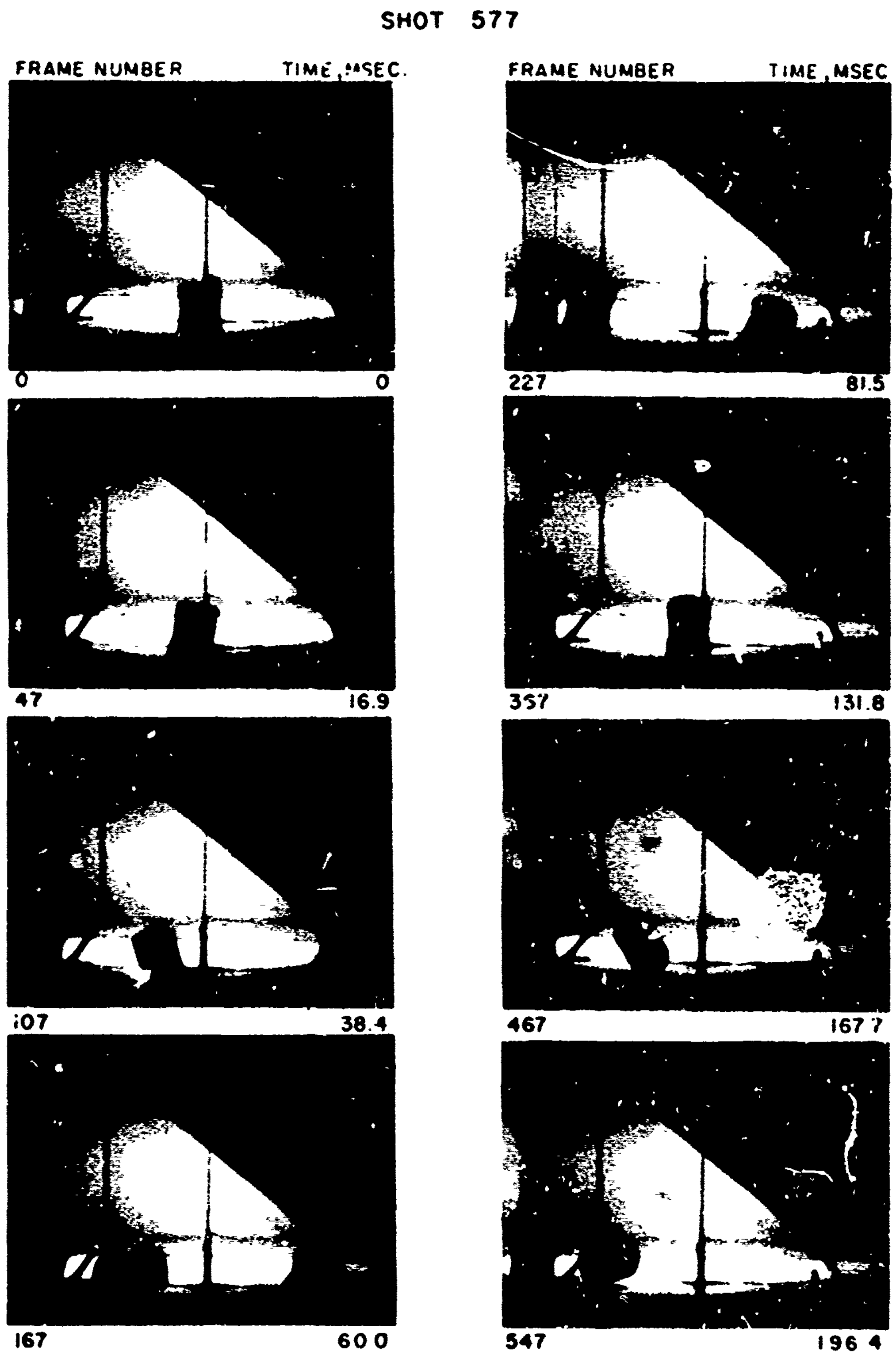


Figure B-17. End View, Cylinders on Row 5--20.2 psi

SHOT 577

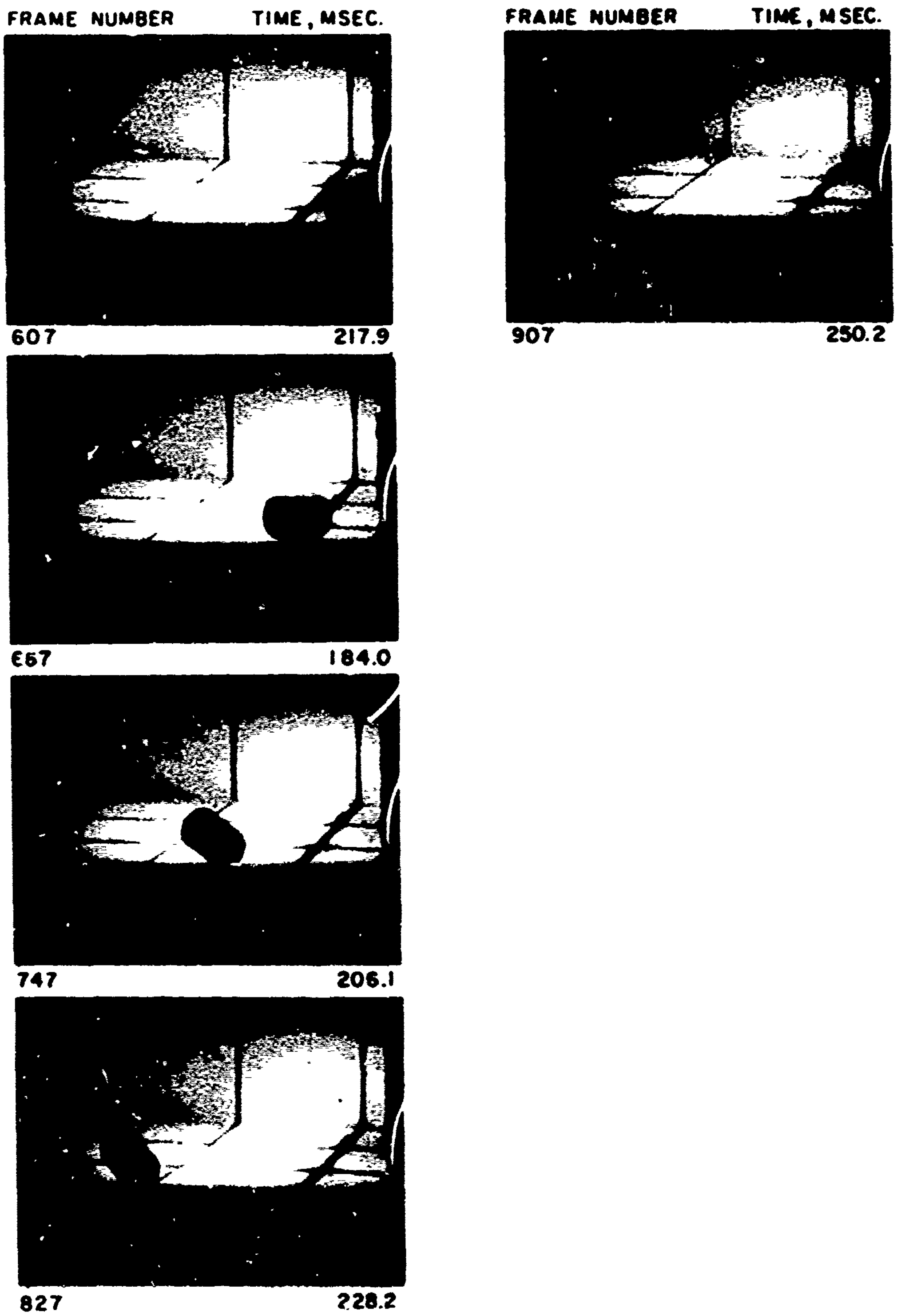


Figure B-18. Side View, Cylinders on Row 5--20.2 psi

APPENDIX C

HIGH SPEED PHOTOGRAPHS-MODEL 42

SHOT 5-73-3

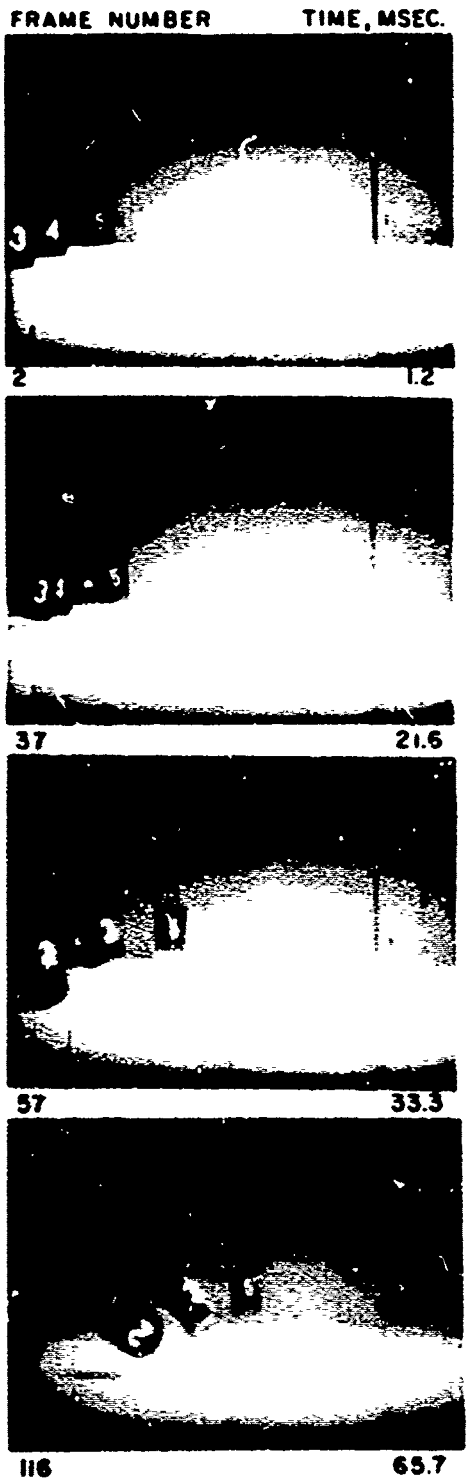


Figure C-1   Camera 1, Side View Model 42--5 psi

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SHOT 5-73-3

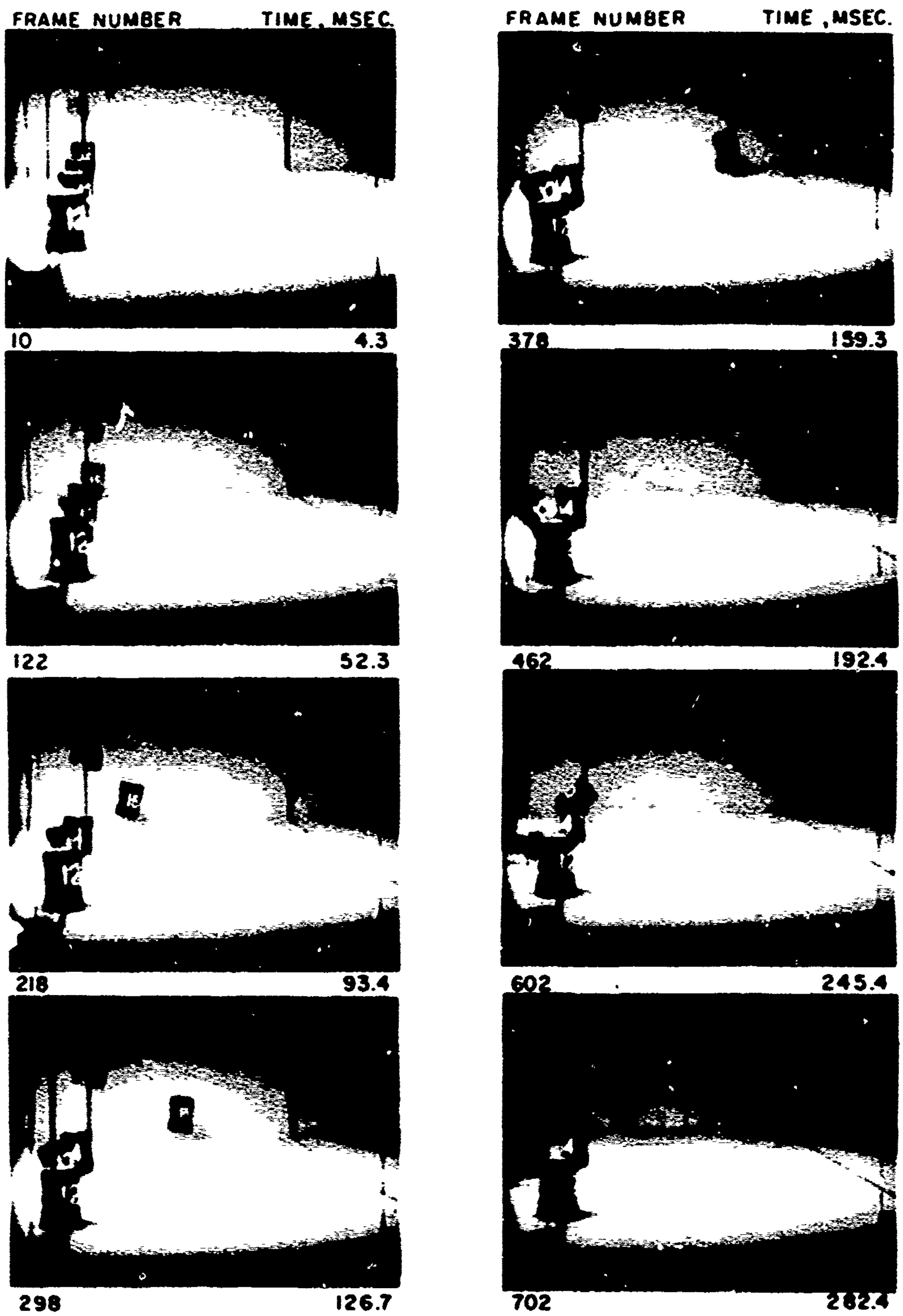


Figure C-2. Camera 2, Side View Model 42--5 psi

SHOT 5-73-3

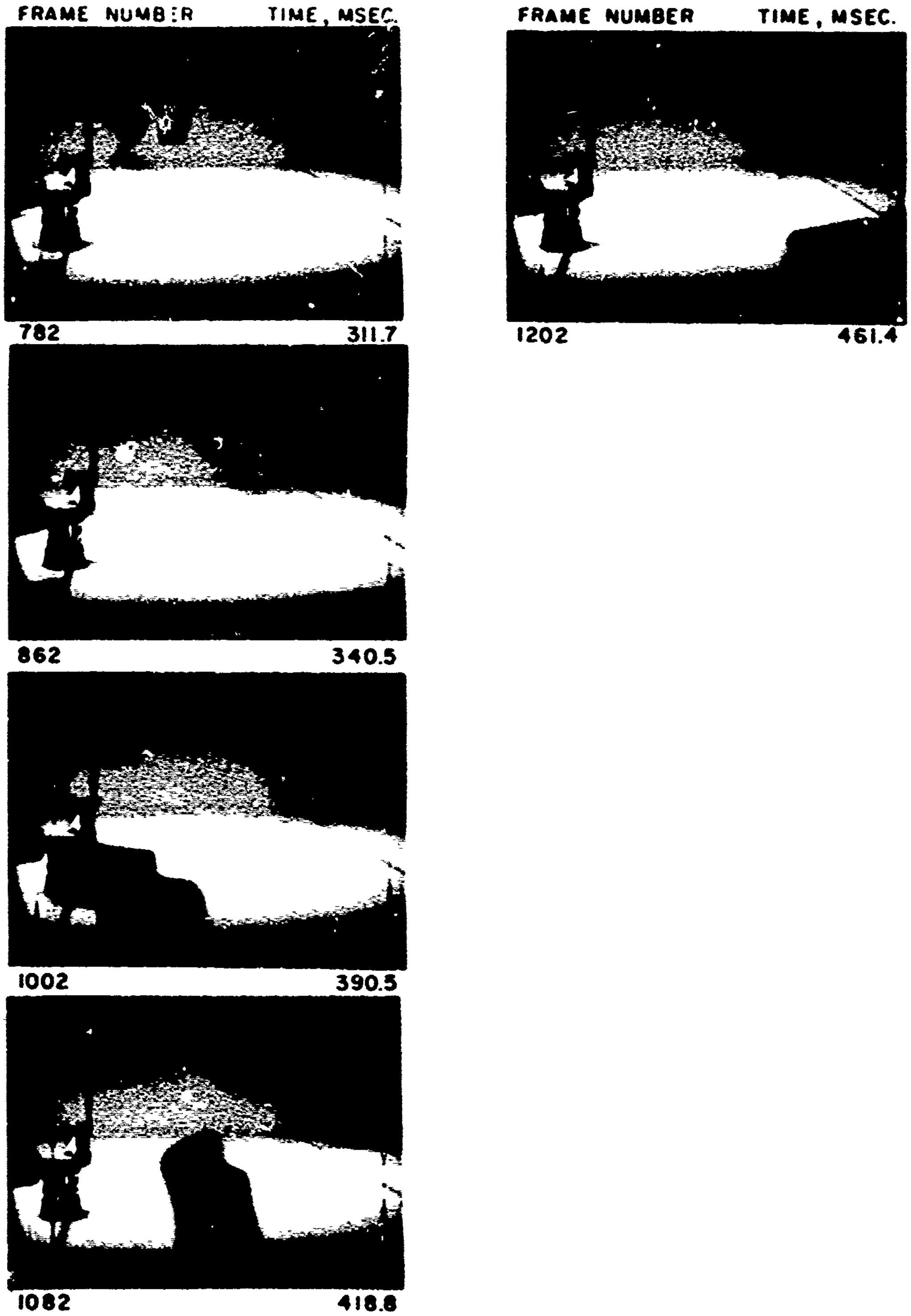


Figure C-2. Continued

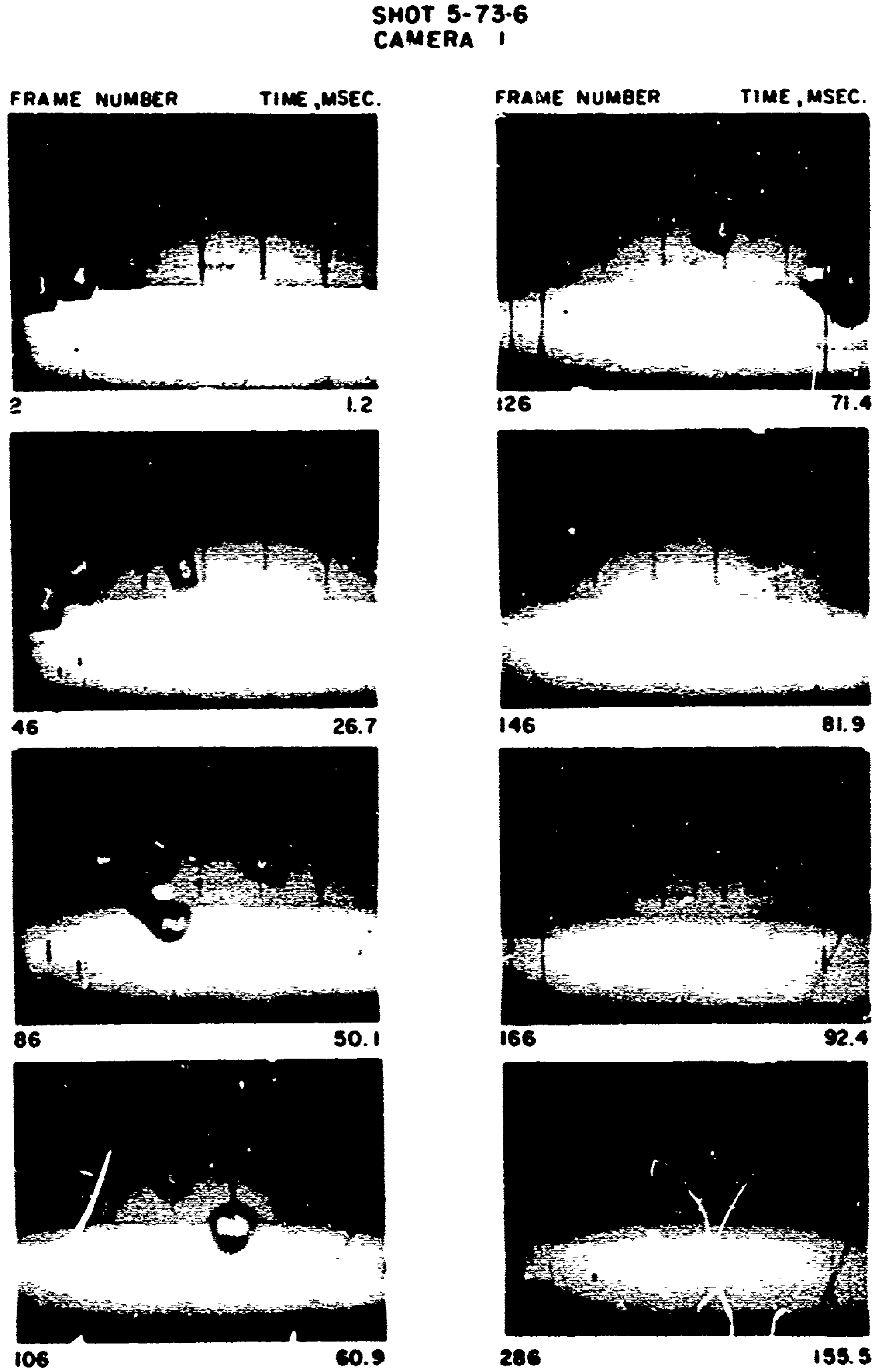


Figure C-3. Camera 1, Side View Model 42--10 psi

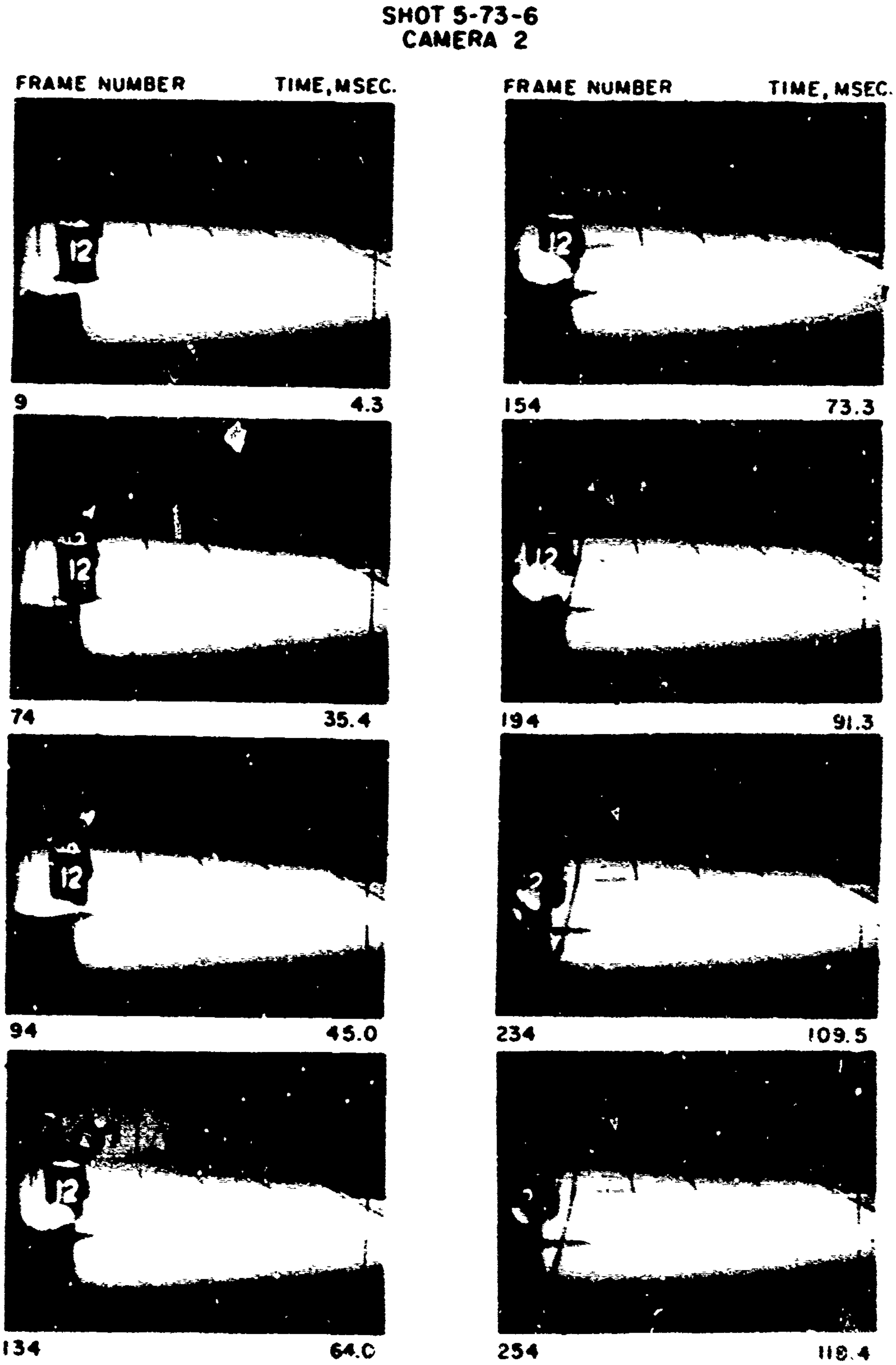


Figure C-4. Camera 2, Side View Model 42--10 psi

SHOT-5-73-6
CAMERA 2

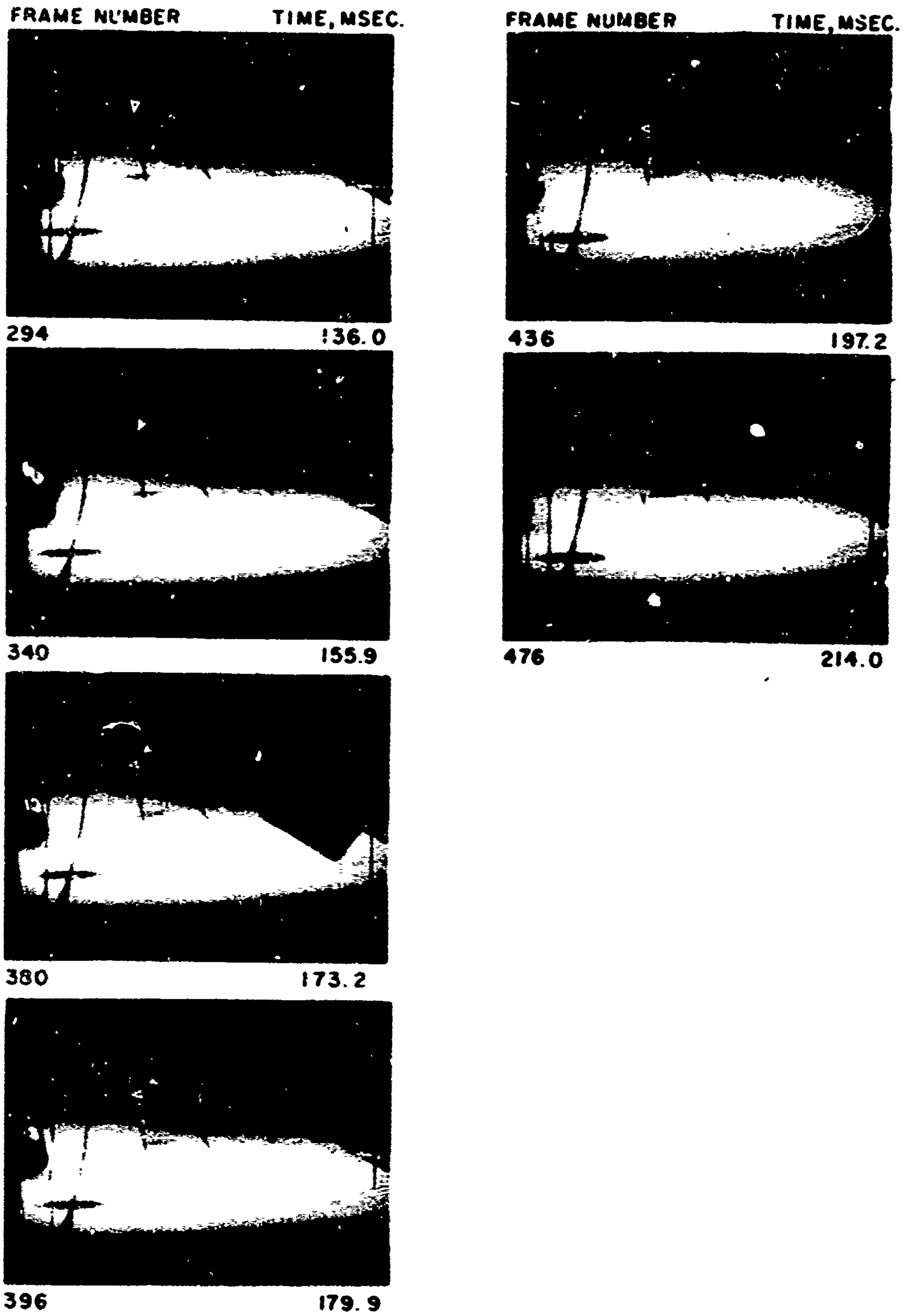


Figure C-4. Continued

APPENDIX D

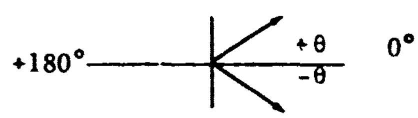
PREDICTION OF VELOCITY FIELDS-MODEL 40

Table D-I. Input Parameters for RIPPLE Code Predictions--Model 4

Input shock pressure, 10 psi
Shock density, 0.00 3349 slugs/ft^3
Shock particle speed, 436.4 ft/sec
Shock temperature, 159.48°F
Shock sound speed, 1219.3 ft/sec
Ambient pressure, 14.7 psi
Ambient termperature, 72°F
Ambient sound speed, 1129.9 ft/sec
Ambient density of air, 0.002321 slugs/ft^3
Ambient air speed, 0.0ft/sec

Notes--1. Model was assumed to be two-dimensional for purpose of RIPPLE predictions.

2. Angle of flow is positive in upper quadrants and negative in lower quadrants.



3. Time equals zero at room side of entrance.

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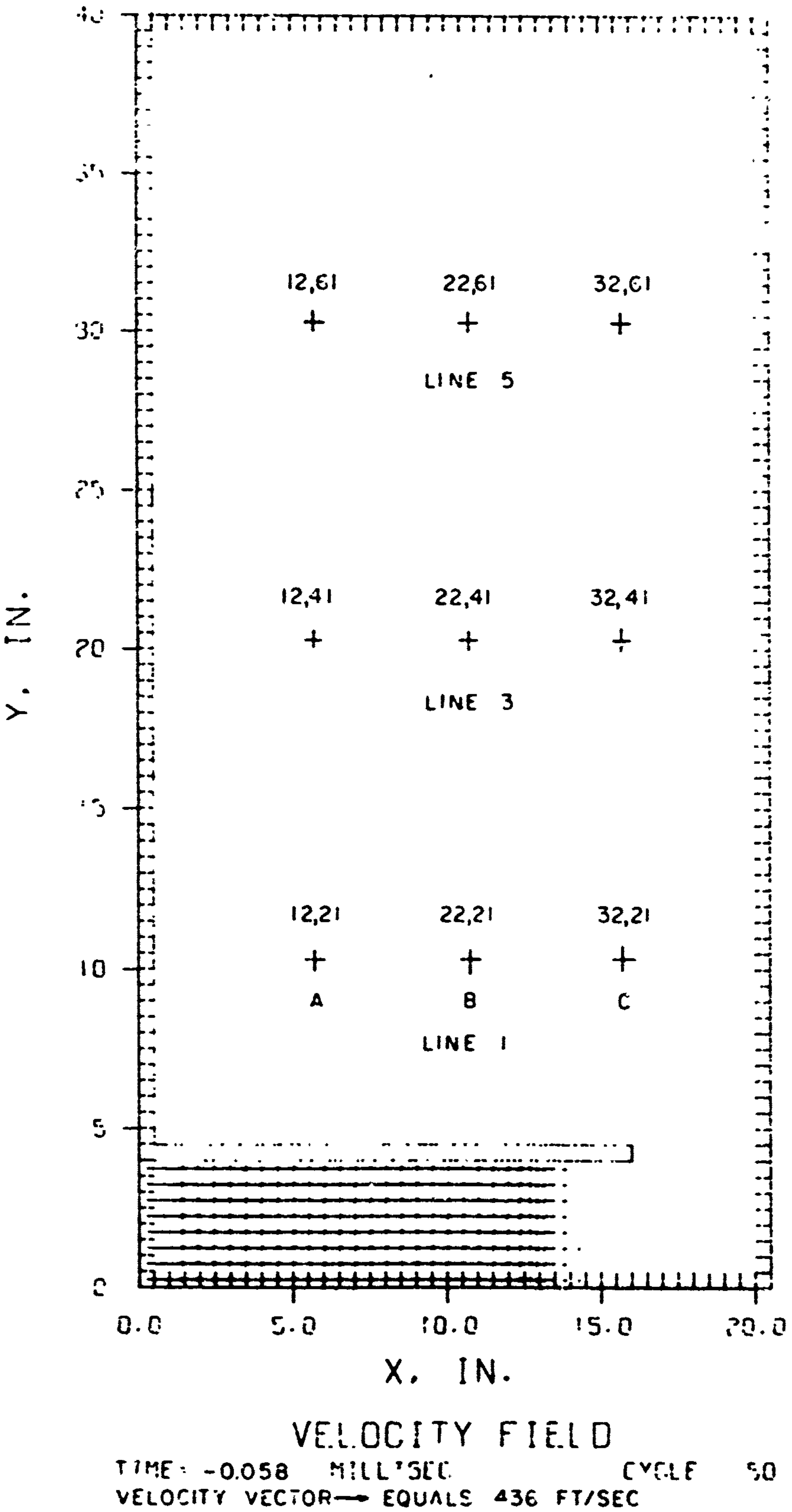


Figure D-1. Velocity Field at -0.058 milliseconds

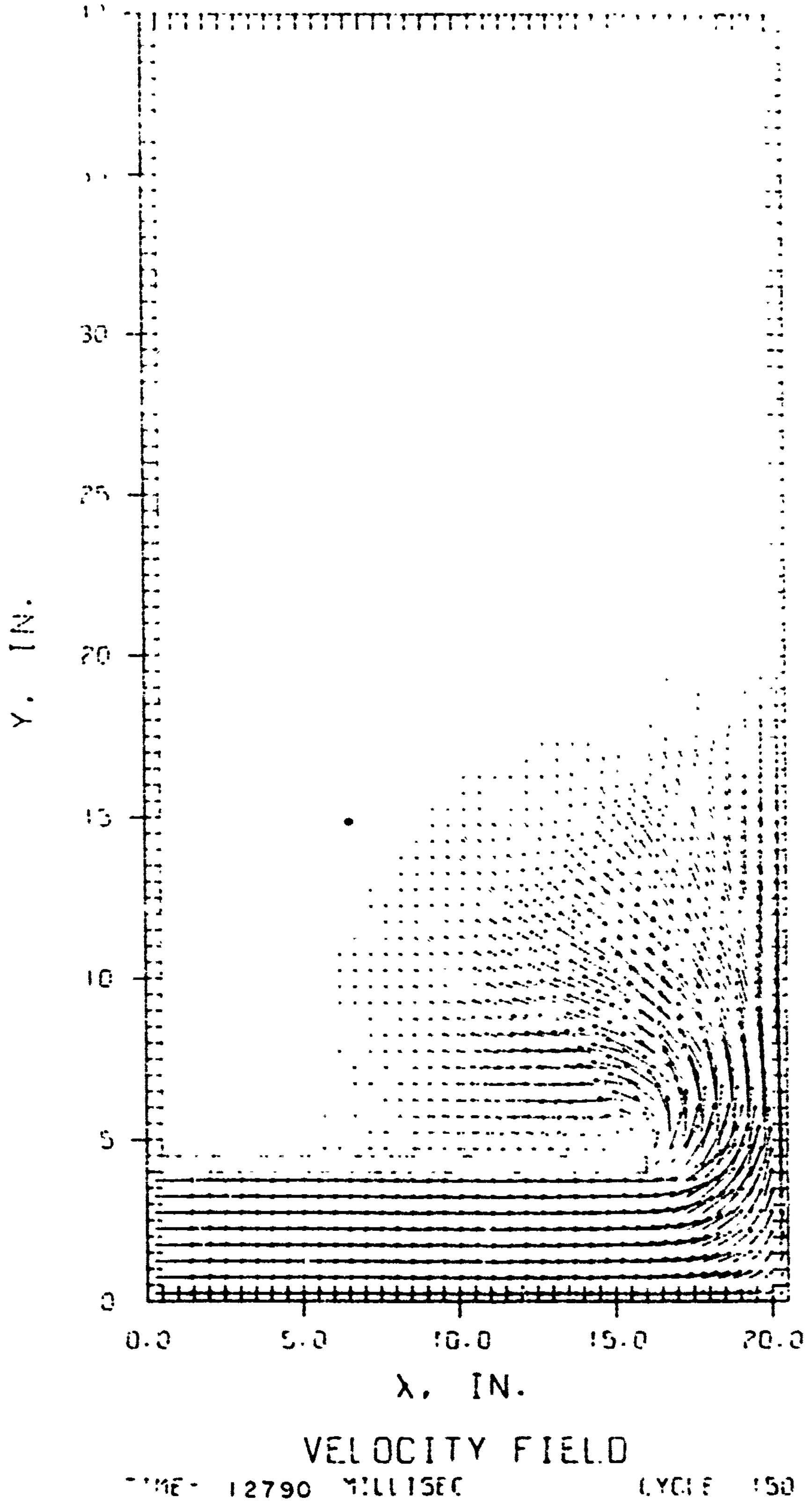


Figure D-2. Velocity Field at 1.28 milliseconds

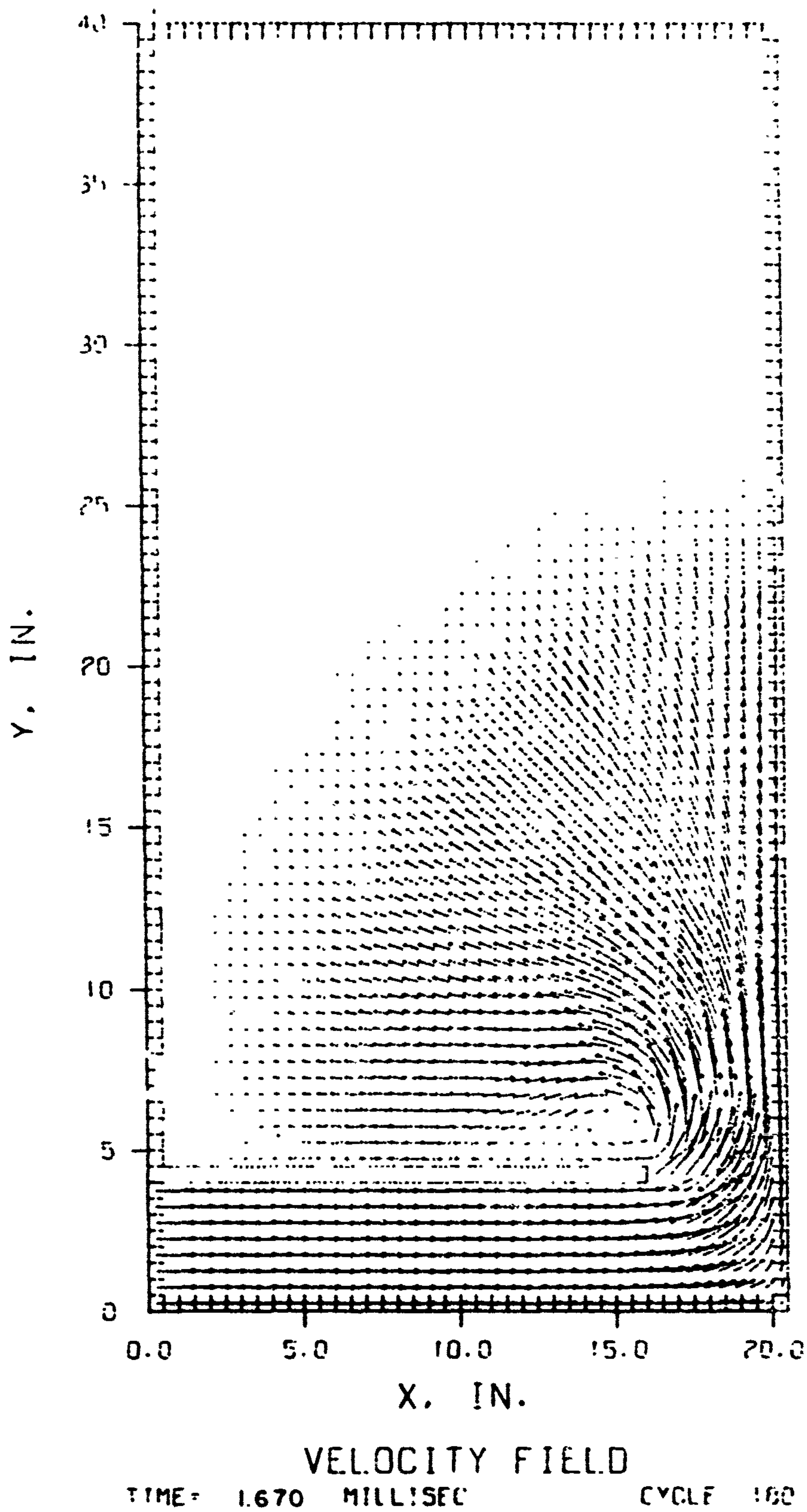


Figure D-3. Velocity Field at 1.67 milliseconds

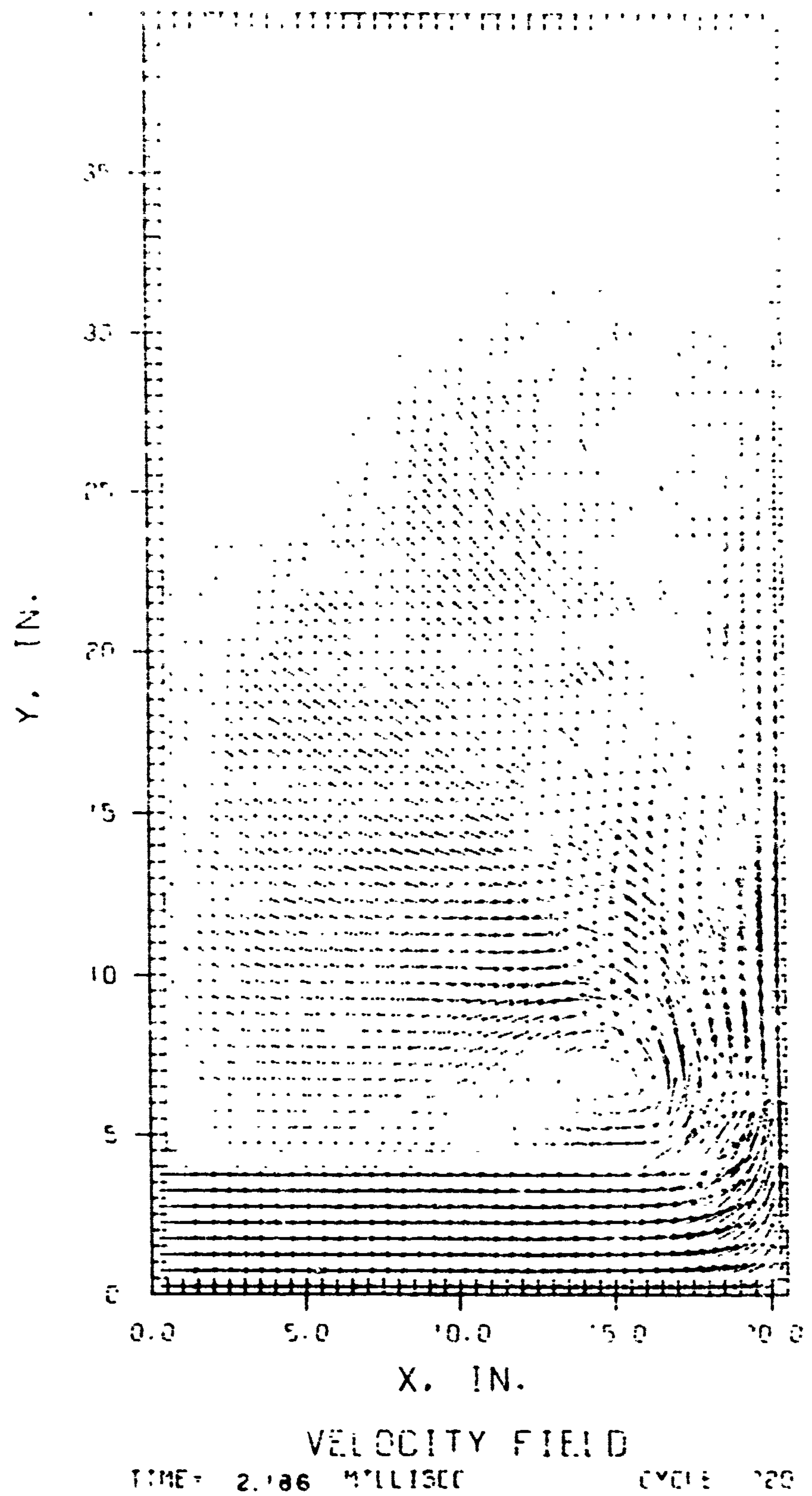


Figure D-4. Velocity Field at 2.19 milliseconds

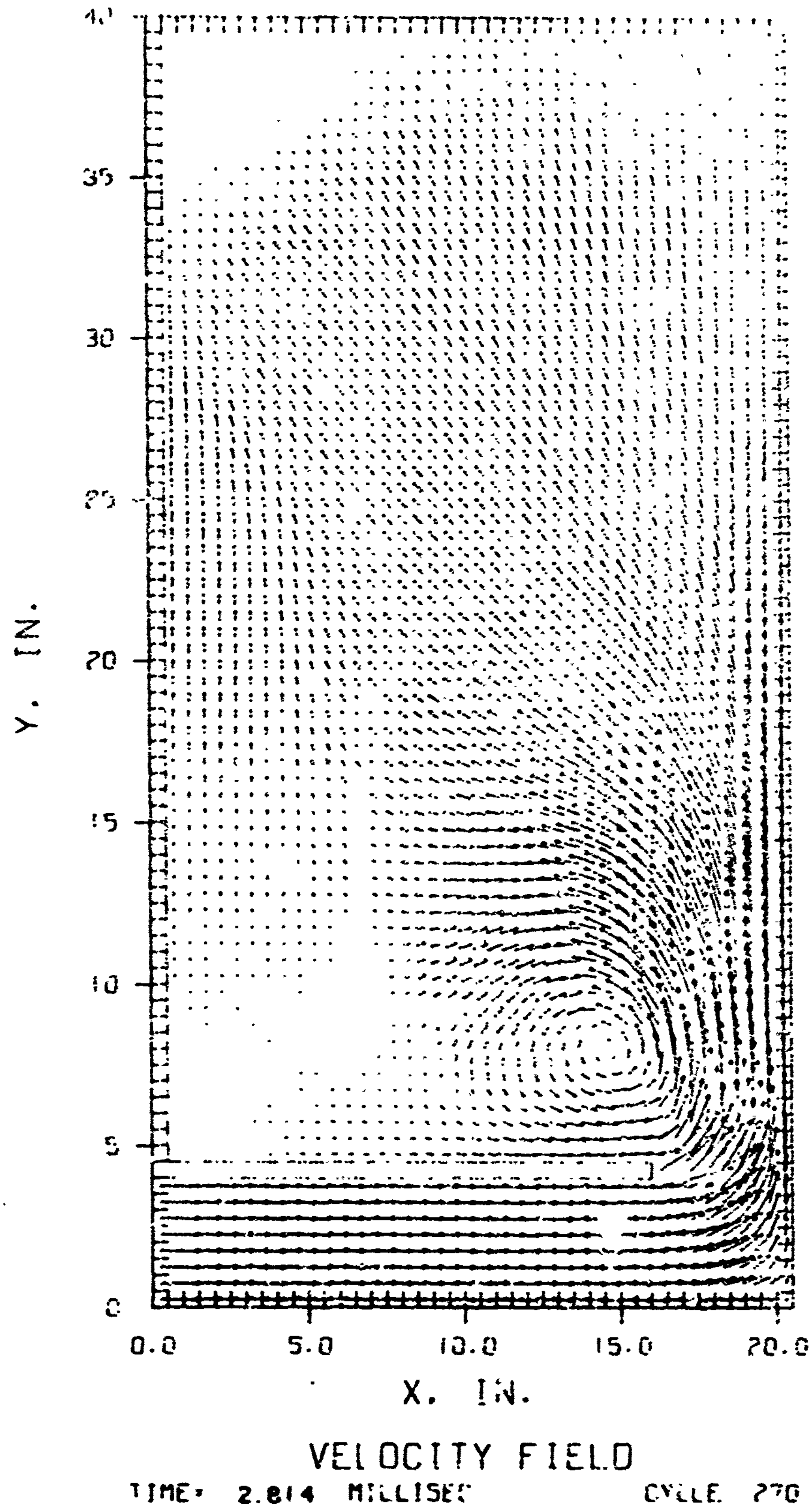


Figure D-5. Velocity Field at 2.81 milliseconds

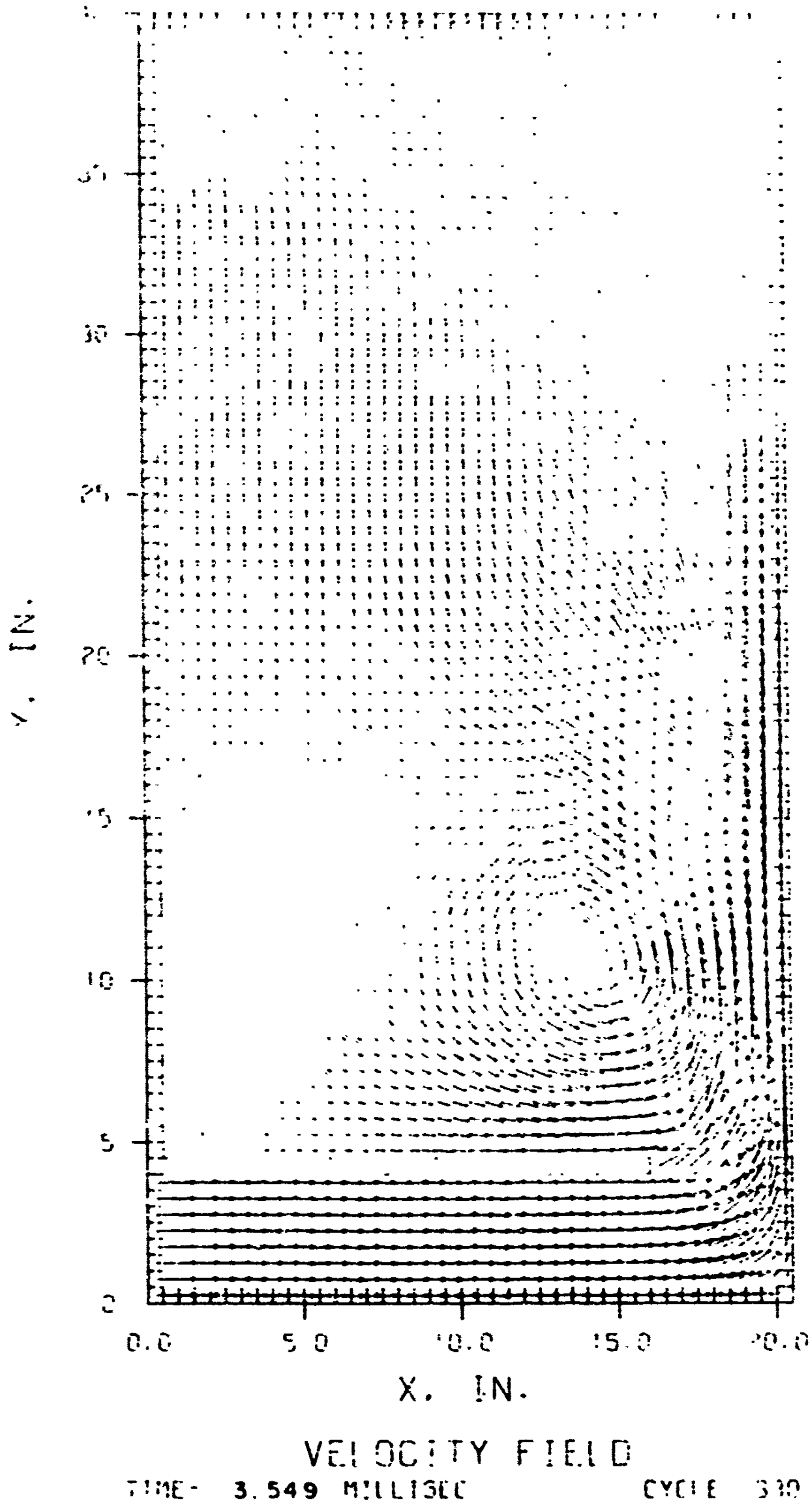


Figure D-6. Velocity Field at 3.55 milliseconds

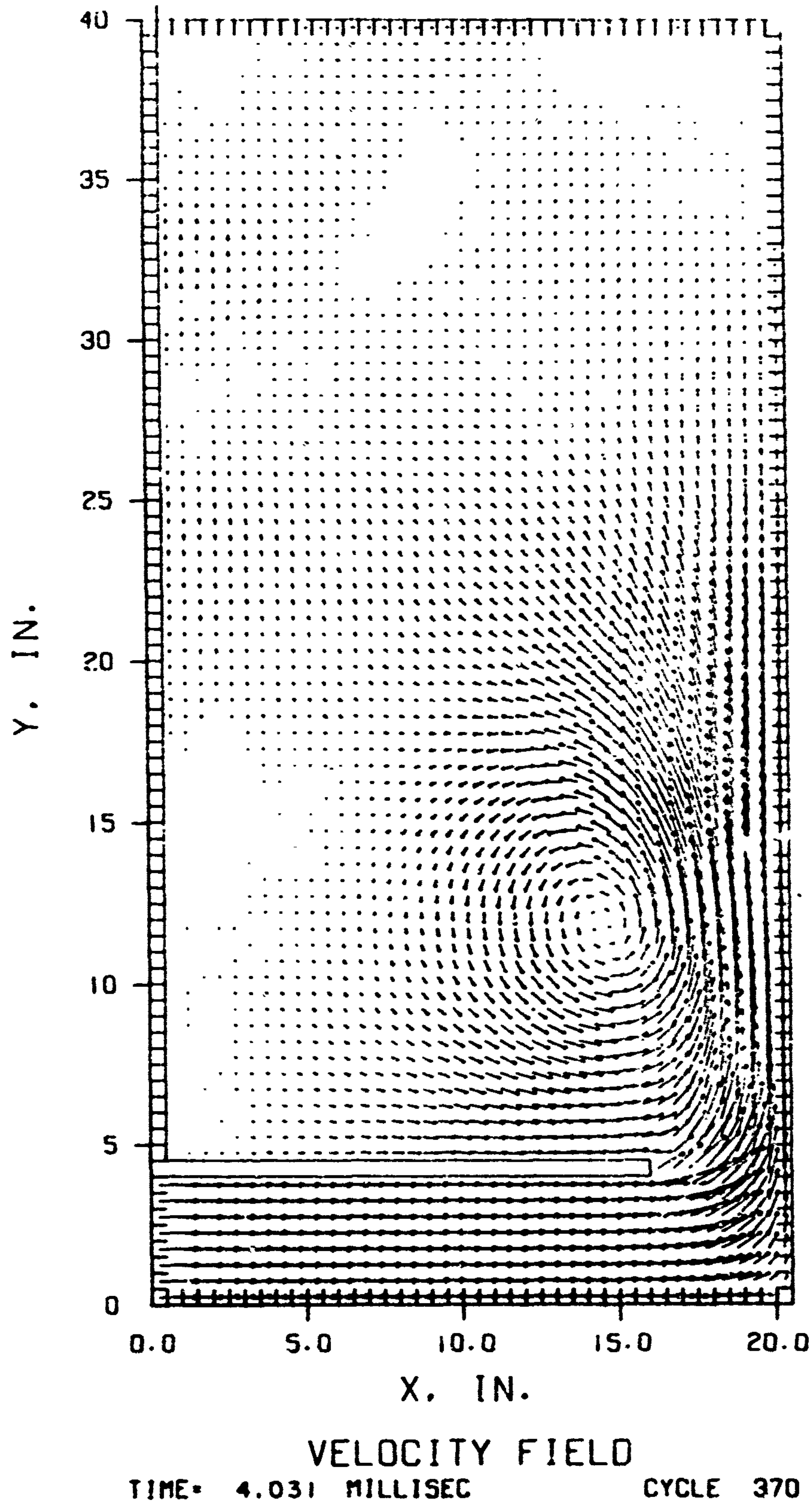


Figure D-7. Velocity Field at 4.03 milliseconds

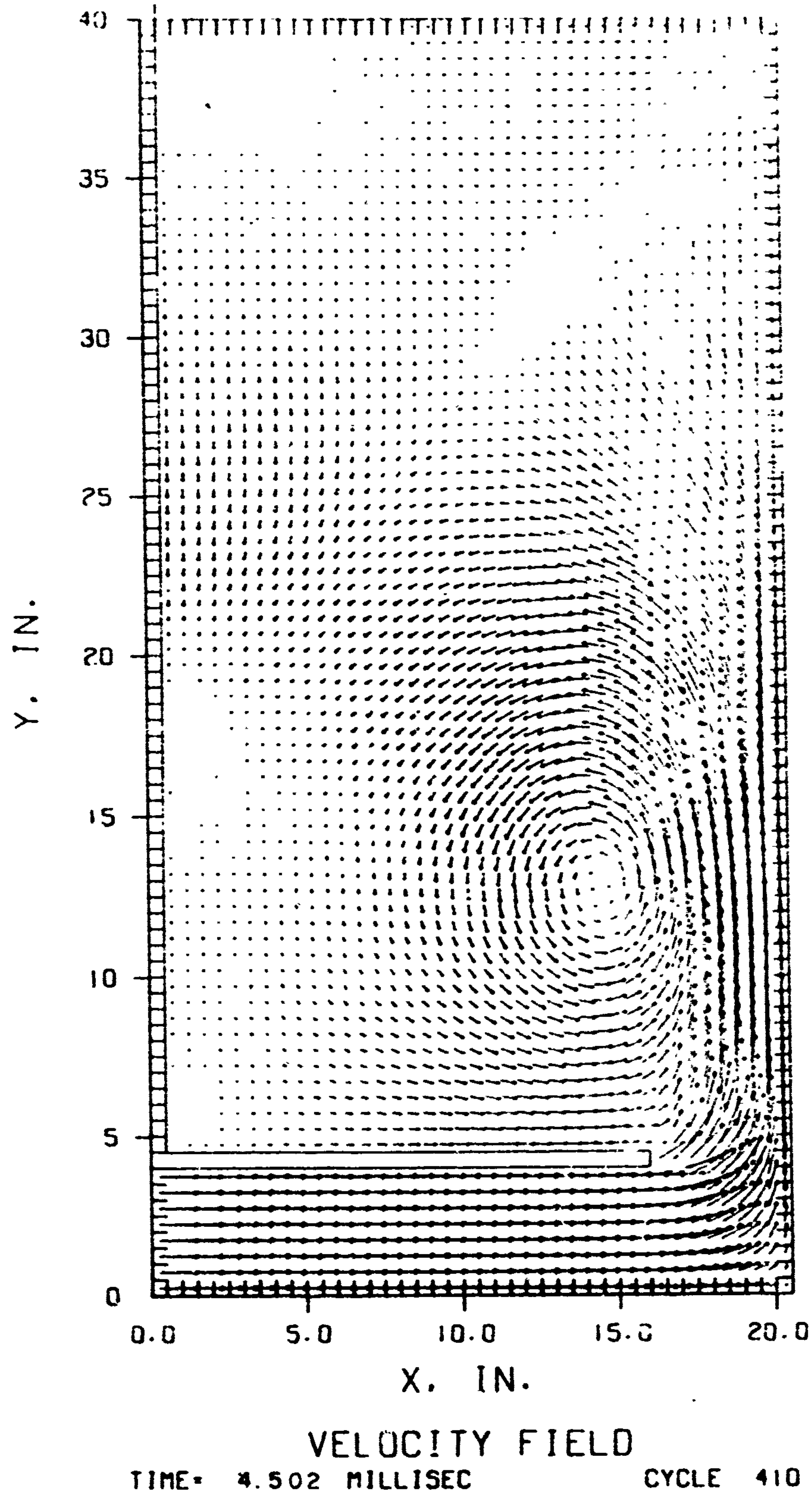


Figure D-8. Velocity Field at 4.50 milliseconds

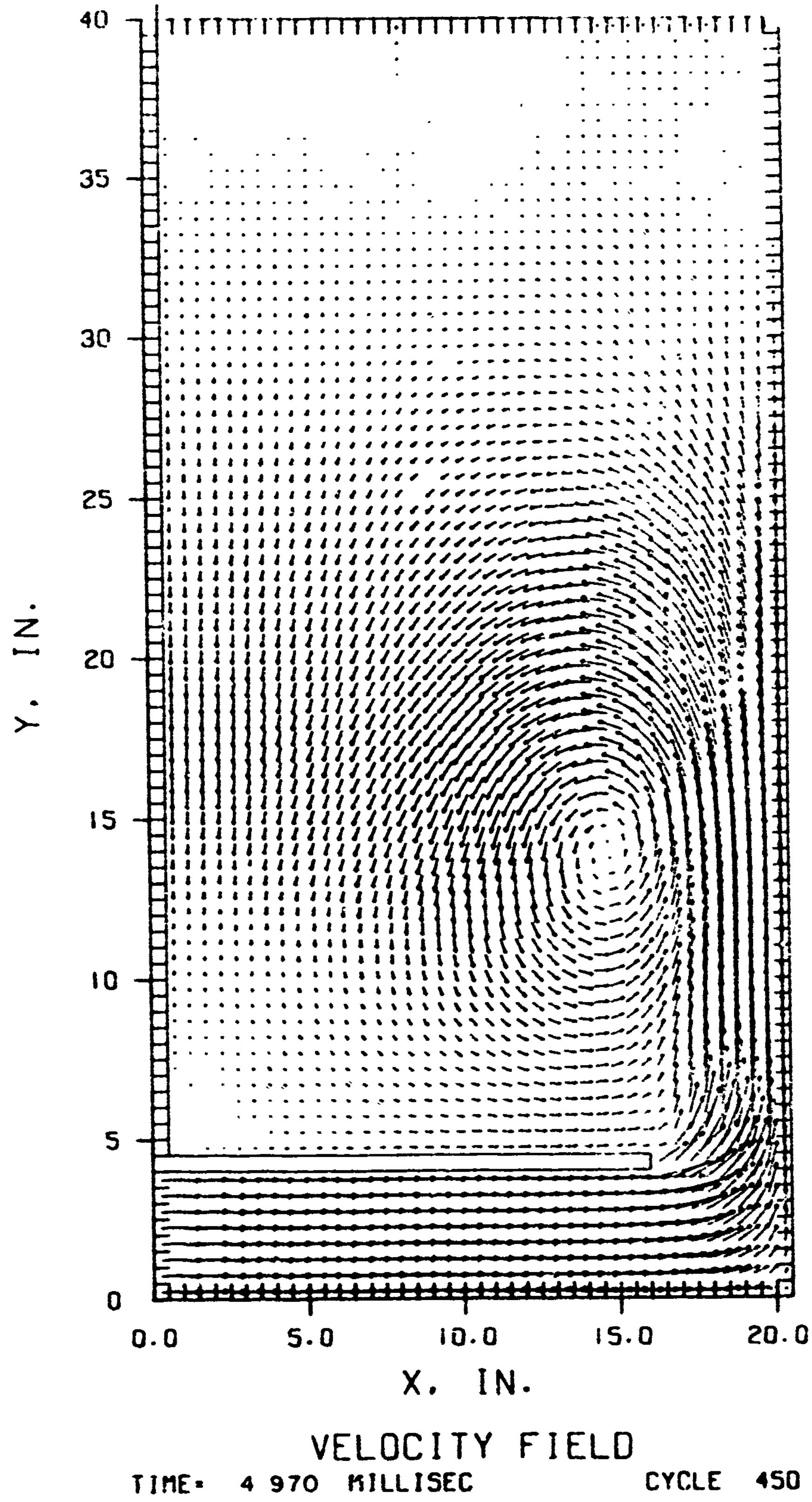


Figure D-9. Velocity Field at 4.97 milliseconds

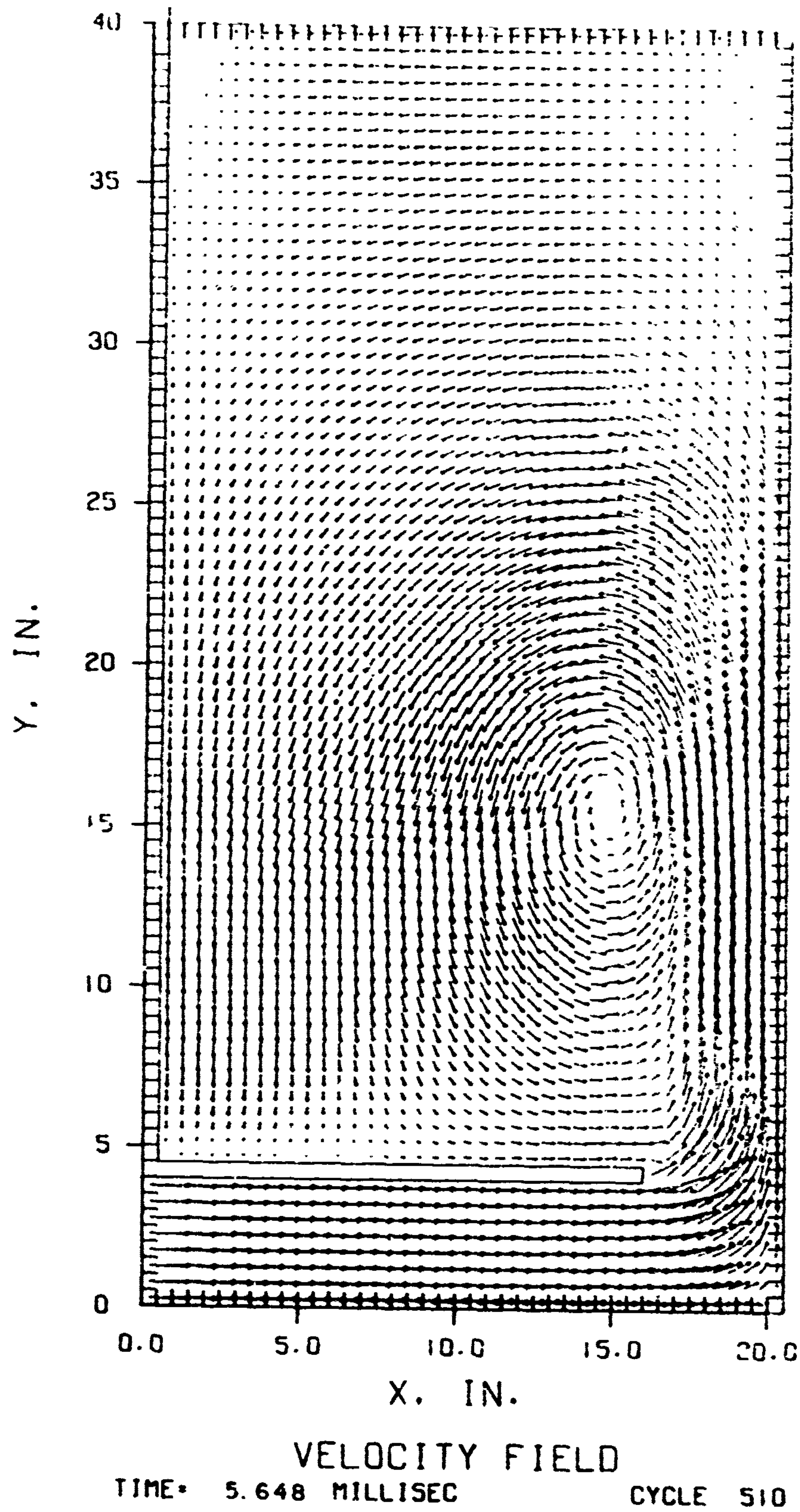


Figure D-10. Velocity Field at 5.65 milliseconds

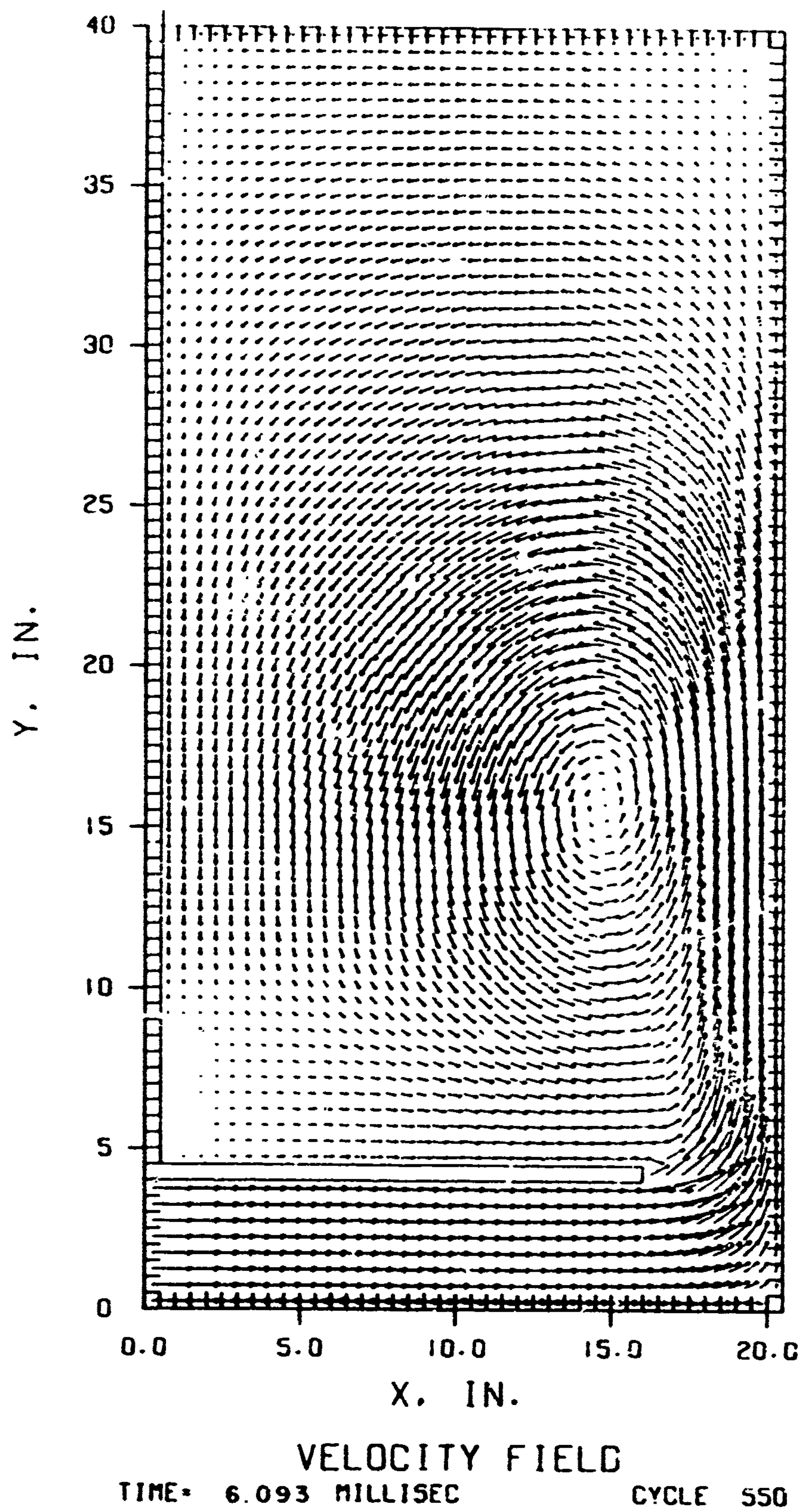


Figure D-11. Velocity Field at 6.09 milliseconds

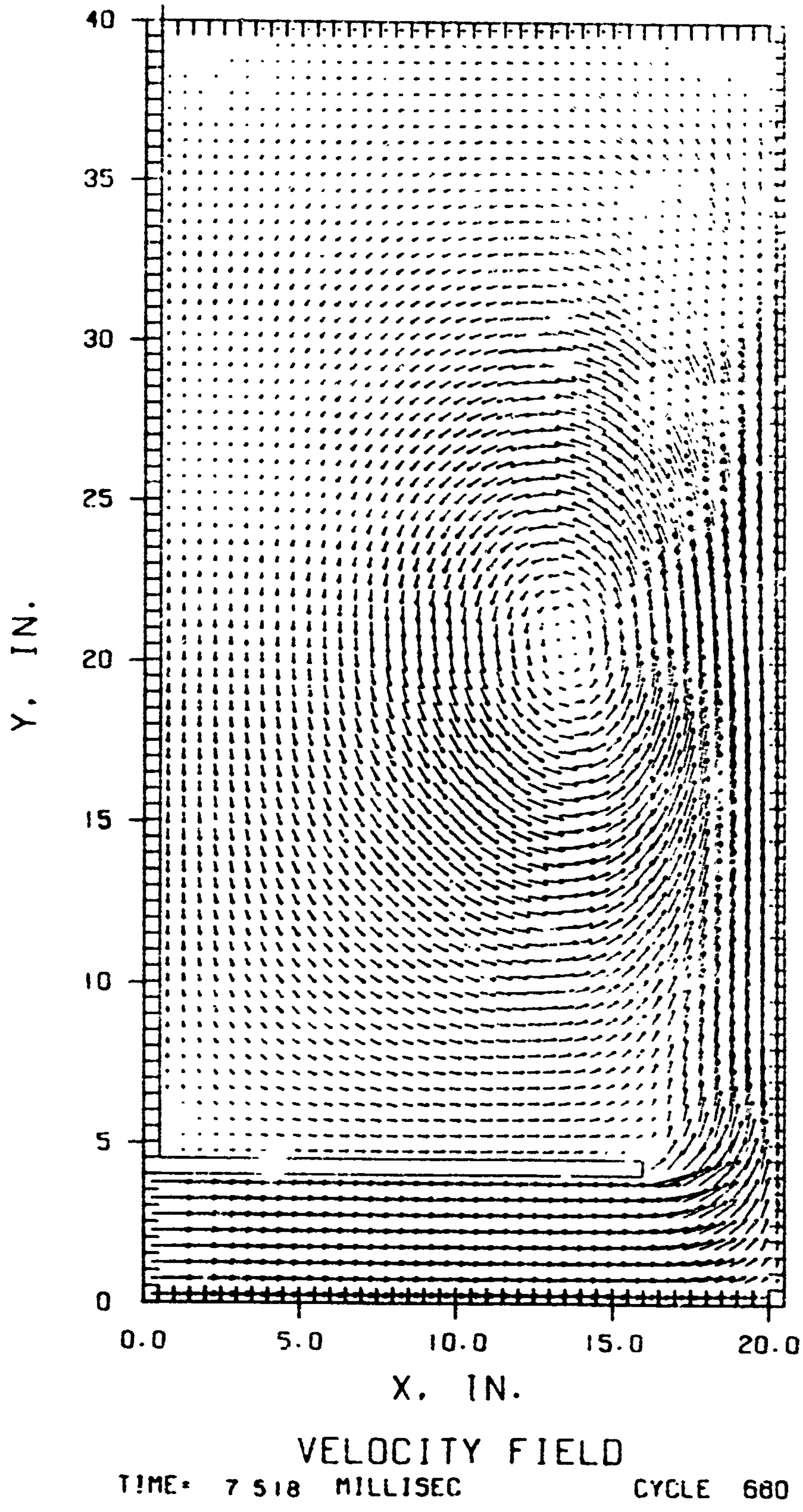


Figure D-12. Velocity Field at 7.52 milliseconds

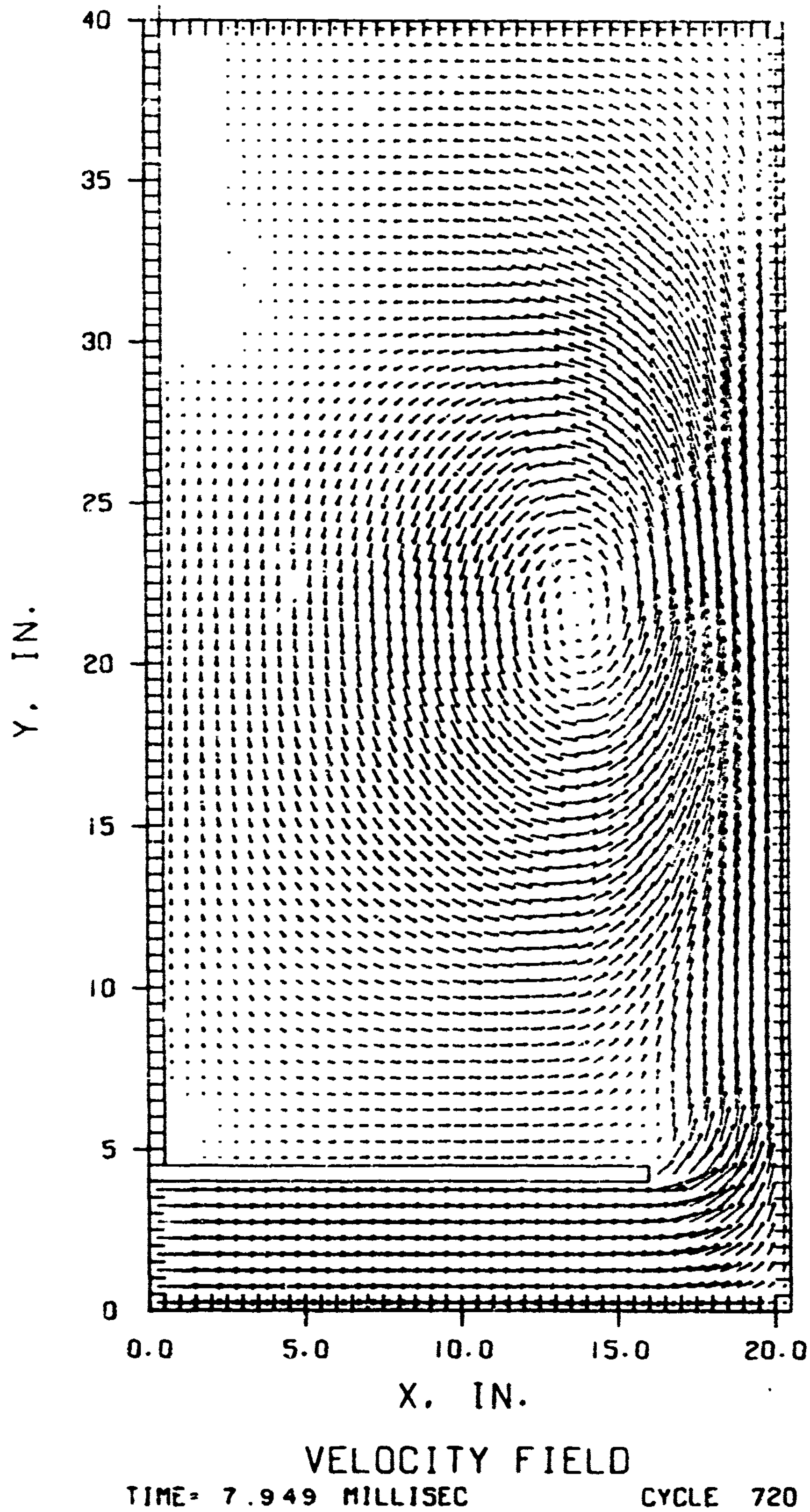


Figure D-13. Velocity Field at 7.95 milliseconds

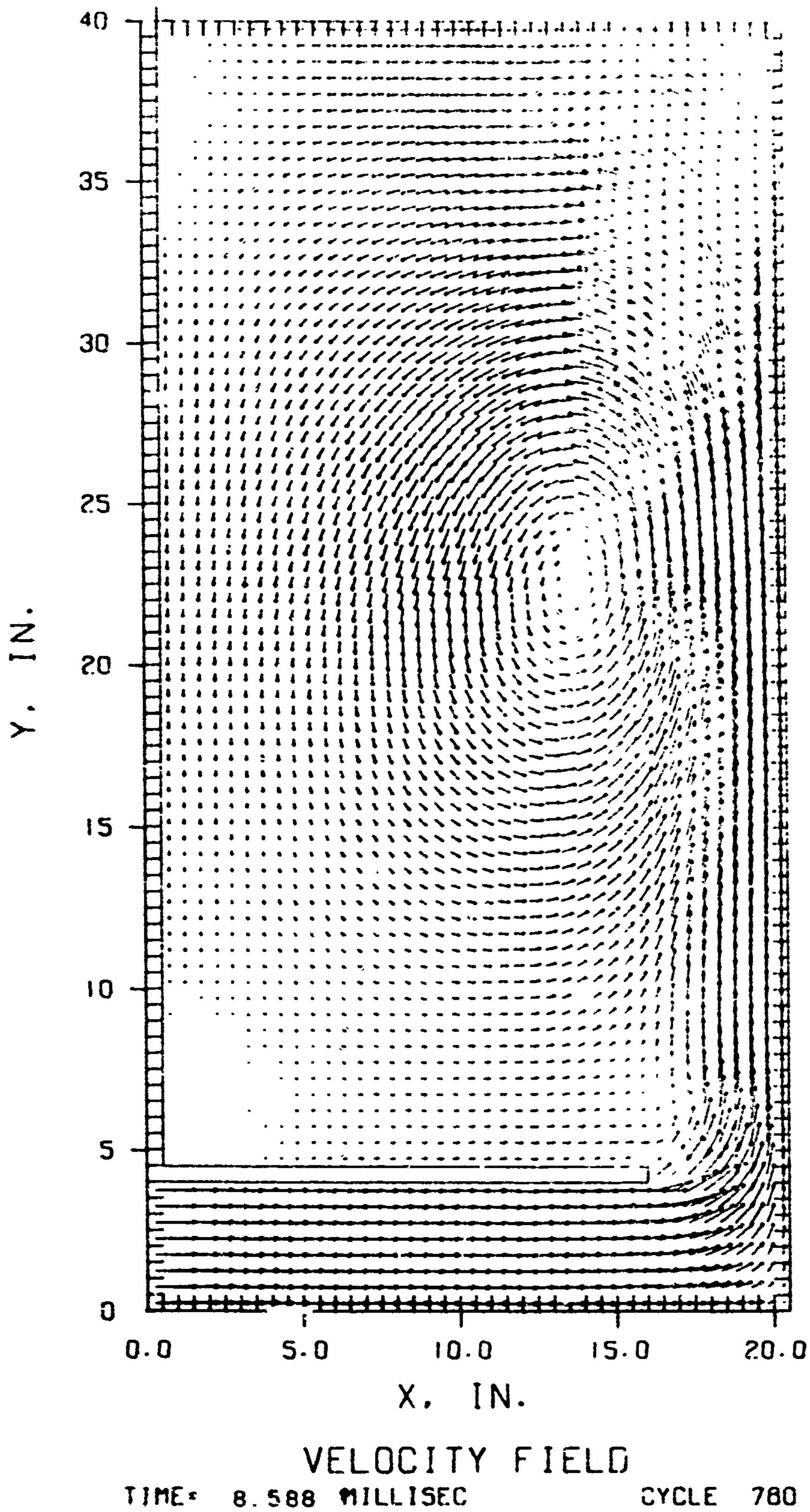


Figure D-14. Velocity Field at 8.59 milliseconds

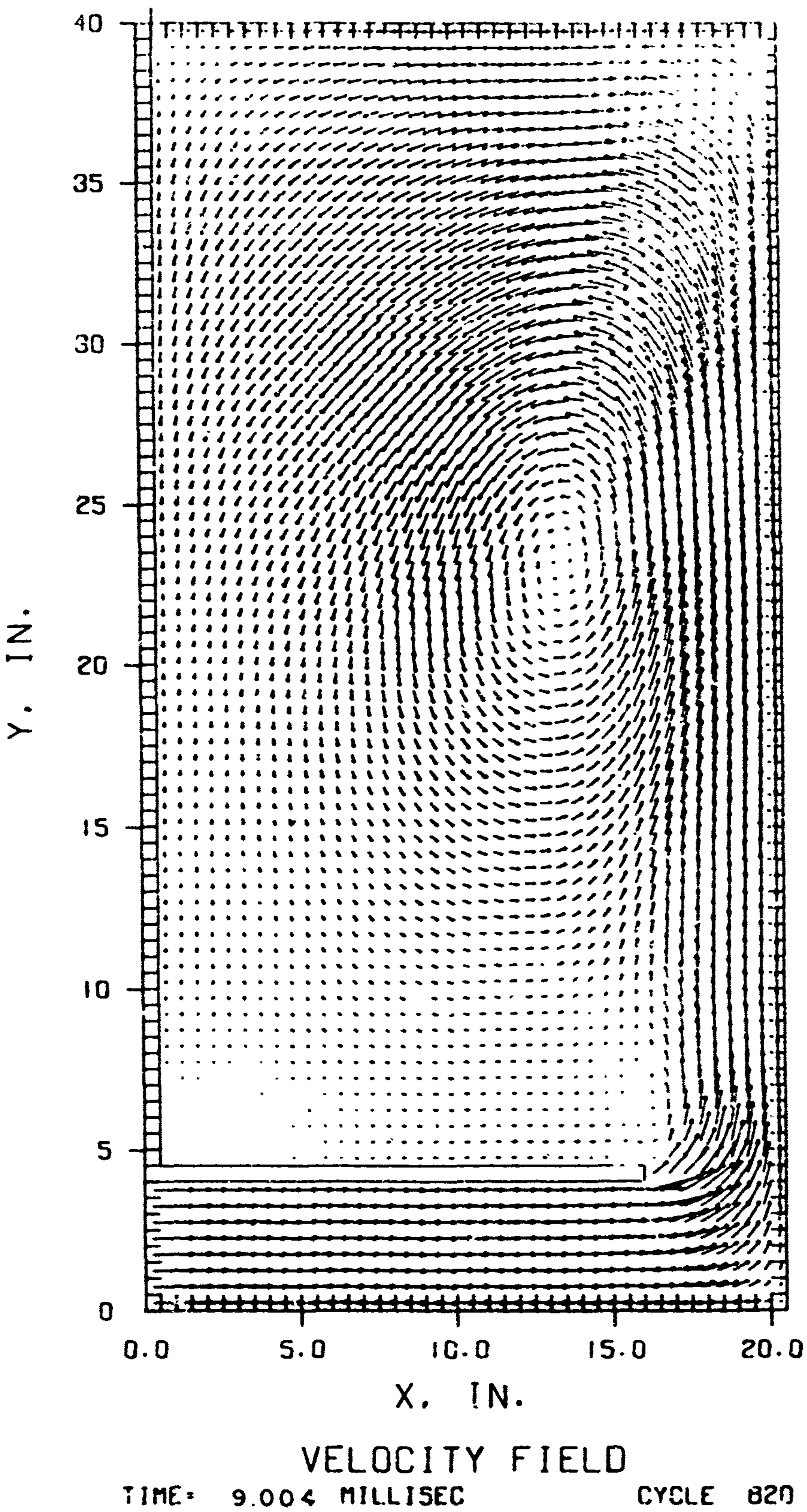


Figure D-15. Velocity Field at 9.00 milliseconds

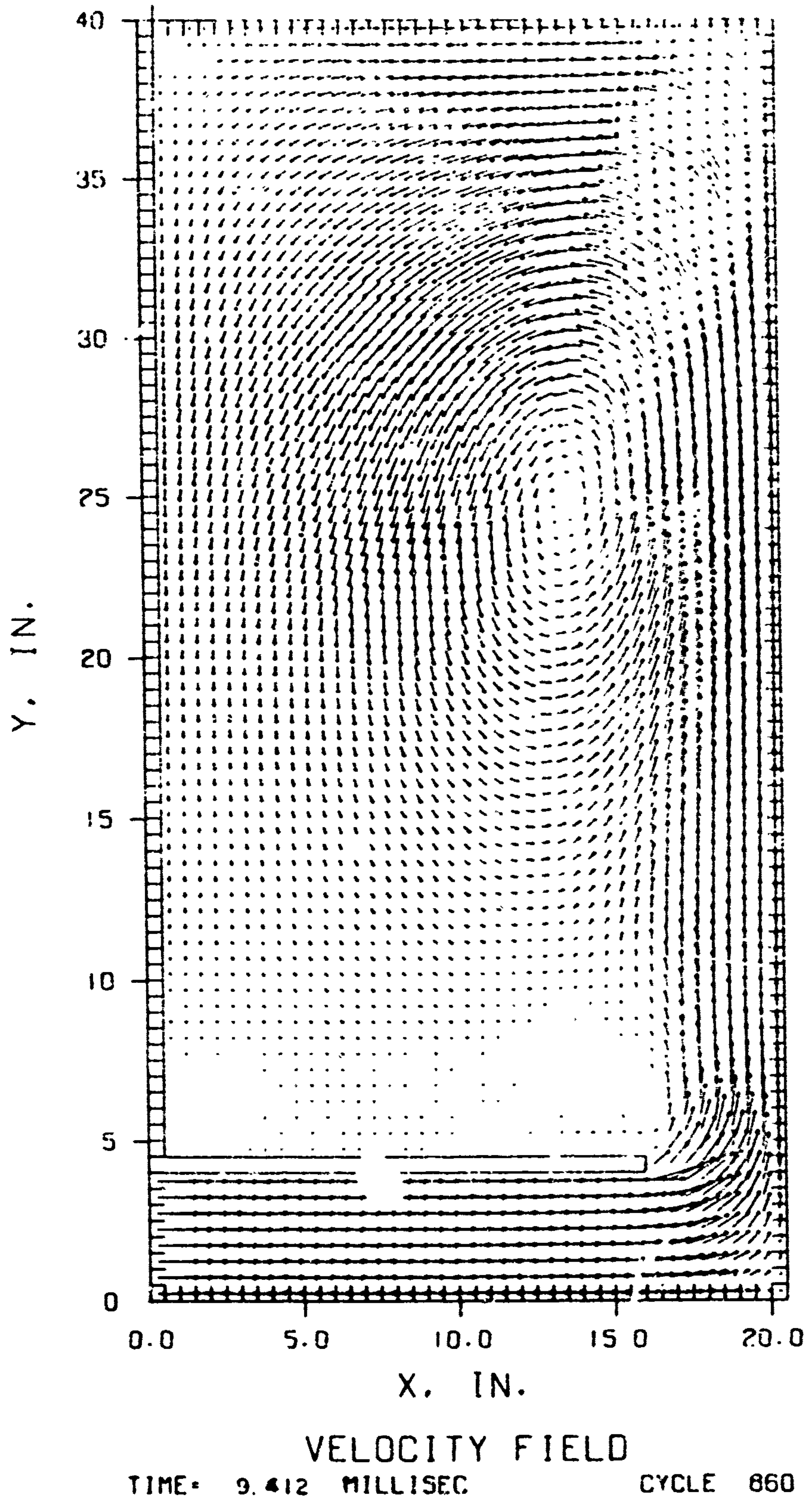


Figure D-16. Velocity Field at 9.41 milliseconds

Table D-II. Flow Parameters Predicted by RIPPLE Code-Model 40

Time msec	Cell No. x	Cell No. y	Air Speed ft/sec	Angle of Flow degrees	Density slugs/ft^3	Dynamic Pressure lb/ft^2	Remarks
1.28	12	21	16.5	160.4	0.00236	0.3	Pos.A
		41	0.02	135.5	0.00232	0	Input pressure, P_s=10psi
		61	0	125.0	0.00232	0	
	22	21	85.5	159.4	0.00251	9.2	Pos.B
		41	1.8	124.0	0.00233	0	P_{center} = 0.03 psi
		61	0	115.5	0.00232	0	
	32	21	306.0	149.2	0.00273	127.9	Pos.C
		41	16.4	101.8	0.00235	0.3	
		61	0	90.1	0.00232	0	
1.67	12	21	74.0	166.6	0.00250	6.8	
		41	8.1	136.9	0.00234	.1	
		61	0	125.7	0.00232	0	
	22	21	200.9	167.4	0.00280	56.5	P_{center}=0.95 psi
		41	55.6	129.1	0.00244	3.8	
		61	0	114.2	0.00232	0	
	32	21	342.0	156.7	0.00237	138.3	
		41	181.4	117.6	0.00267	44.0	
		61	0.4	95.3	0.00232	0	
2.19	12	21	111.7	168.4	0.00273	17.1	
		41	146.0	145.3	0.00268	28.5	
		61	10.3	125.7	0.00234	0.1	
	22	21	169.4	174.3	0.00276	39.6	P_{center}=2.29 psi
		41	162.1	139.9	0.00262	34.4	
		61	65.6	119.4	0.00246	5.3	
	32	21	332.7	156.2	0.00225	124.7	
		41	195.9	122.4	0.00250	48.0	
		61	133.6	107.5	0.00258	23.1	

Table D-II. Flow Parameters Predicted by RIPPLE Code-Model 40 (Continued)

Time msec	Cell No. x	Cell No. y	Air Speed ft/sec	Angle of Flow degrees	Density slugs/ft^3	Dynamic Pressure lb/ft^2	Remarks
2.81	12	21	13.3	56.5	0.00292	0.3	
		41	89.4	101.4	0.00284	11.4	
		61	127.5	125.0	0.00263	21.4	
	22	21	103.4	-141.3	0.00284	15.2	P_{center} = 1.18 psi
		41	141.5	144.3	0.00258	25.8	
		61	132.8	123.4	0.00255	22.5	
	32	21	266.5	145.2	0.00216	76.7	
		41	209.6	129.3	0.00229	50.4	
		61	140.0	109.7	0.00250	24.7	
3.55	12	21	21.5	-47.6	0.00275	0.6	
		41	62.8	102.5	0.00278	5.5	
		61	111.6	88.2	0.00276	17.2	
	22	21	106.1	-64.0	0.00287	16.2	P_{center} = 2.67 psi
		41	84.8	123.3	0.00280	10.1	
		61	96.0	94.8	0.00273	12.6	
	32	21	144.7	60.6	0.00244	25.6	
		41	231.4	127.6	0.00207	55.3	
		61	89.1	121.1	0.0025[illegible]	10.6	
4.03	12	21	40.1	-48.8	0.00265	2.1	
		41	41.8	121.3	0.00273	2.4	
		61	28.8	-157.5	0.00296	1.2	
	22	21	131.7	-49.8	0.00274	23.7	P_{center} = 1.99 psi
		41	83.7	159.1	0.00278	9.7	
		61	33.9	143.3	0.00285	1.6	
	32	21	203.9	22.9	0.00249	51.6	
		41	237.7	132.5	0.00201	56.7	
		61	55.7	91.8	0.00273	4.2	

Table D-II. Flow Parameters Predicted by RIPPLE Code-Model 40 (Continued)

Time msec	Cell No. x	Cell No. y	Air Speed ft/sec	Angle of Flow degrees	Density $slugs/ft^3$	Dynamic Pressure lb/ft^2	Remarks
4.50	12	21	49.4	-4.8	0.00258	3.2	
		41	48.1	-146.7	0.00282	3.3	
		61	57.6	-83.2	0.00301	5.0	
	22	21	130.5	-45.2	0.00269	22.9	P_{center} = 2.94 psi
		41	137.9	-152.7	0.00292	27.8	
		61	21.6	-93.8	0.00292	0.7	
	32	21	201.0	29.1	0.00253	51.1	
		41	262.9	159.7	0.00231	79.9	
		61	74.7	115.7	0.00271	7.6	
4.97	12	21	68.1	-84.6	0.00262	6.1	
		41	154.8	-106.2	0.00314	37.7	
		61	45.2	-112.0	0.00288	2.9	
	22	21	131.9	-67.2	0.00282	24.5	P_{center} = 4.24 psi
		41	229.4	-131.4	0.00306	80.4	
		61	61.6	-165.2	0.00294	5.6	
	32	21	95.8	120.8	0.00271	12.4	
		41	300.9	160.9	0.00258	116.6	
		61	66.4	148.7	0.00279	6.2	
5.65	12	21	172.0	-88.0	0.00303	44.8	
		41	156.2	-116.4	0.00313	38.2	
		61	87.7	-150.7	0.00295	11.3	
	22	21	191.9	-63.6	0.00295	54.2	P_{center} = 3.41 psi
		41	267.7	-127.7	0.00283	101.2	
		61	139.8	-162.2	0.00296	28.9	
	32	21	152.1	20.4	0.00269	31.0	
		41	263.9	166.7	0.00274	85.5	
		61	131.7	170.6	0.00269	23.3	

Table D-II. Flow Parameters Predicted by RIPPLE Code-Model 40 (Continued)

Time msec	Cell No. x	Cell No. y	Air Speed ft/sec	Angle of Flow degrees	Density slugs/ft^3	Dynamic Pressure lb/'c^2	Remarks
6.09	12	21	77.8	-58.1	0.00324	9.8	
		41	161.3	-113.3	0.00323	42.0	
		61	120.0	-147.4	0.00311	22.4	
	22	21	161.7	-45.9	0.00301	39.3	P_{center} = 3.46 psi
		41	319.7	-126.6	0.00271	138.4	
		61	16[illegible].6	-163.9	0.00292	39.6	
	32	21	176.5	9.6	0.00280	43.6	
		41	260.4	166.9	0.00270	91.6	
		61	158.8	164.8	0.00251	31.6	
6.42	12	21	79.6	-21.0	0.00326	10.3	
		41	184.7	-114.6	0.00341	58.2	
		61	103.2	-137.8	0.00319	17.0	
	22	21	176.2	-21.3	0.00315	49.0	P_{center} = 3.32 psi
		41	312.9	-122.1	0.00260	127.4	
		61	161.4	-164.7	0.00286	37.3	
	32	21	208.5	18.6	0.00286	62.2	
		41	256.6	156.4	0.00272	89.5	
		61	186.3	161.4	0.00230	39.6	
6.86	12	21	92.2	-48.9	0.00312	13.3	
		41	118.2	-104.8	0.00370	25.9	
		61	86.0	-112.5	0.00326	12.0	
	22	21	194.2	-22.0	0.00307	58.0	P_{center} = 4.14 psi
		41	242.9	-116.1	0.00266	78.5	
		61	139.2	-159.8	0.00288	27.9	
	32	21	224.0	19.4	0.00294	73.7	
		41	241.0	129.2	0.00286	83.2	
		61	212.1	159.4	0.00202	45.4	

Table D-II. Flow Parameters Predicted by RIPPLE Code-Model 40 (Continued)

Time msec	Cell No. x	Cell No. y	Air Speed ft/sec	Angle of Flow degrees	Density slugs/ft^3	Dynamic Pressure lb/ft^2	Remarks
7.06	12	21	101.8	-50.0	0.00308	16.0	
		41	96.3	-90.2	0.00384	17.8	
		51	85.1	-111.8	0.00326	11.8	
	22	21	185.5	-21.8	0.00304	52.2	P_{center} = 4.76 psi
		41	190.5	-107.8	0.00273	49.5	
		61	131.7	-153.9	0.00293	25.4	
	32	21	211.9	23.1	0.00297	66.7	
		41	242.9	112.5	0.00296	87.2	
		61	213.6	159.1	0.00191	43.6	
7.95	12	21	71.9	-25.1	0.00302	7.8	
		41	136.7	-80.9	0.00341	31.9	
		61	47.8	-144.6	0.00344	3.9	
	22	21	127.7	-5.5	0.00309	25.2	P_{center} = 4.49 psi
		41	208.5	-73.5	0.00266	57.9	
		61	144.5	-162.5	0.00298	31.1	
	32	21	152.7	44.7	0.00320	37.3	
		41	222.8	58.5	0.00312	77.6	
		61	266.1	149.8	0.00246	87.1	
8.59	12	21	38.3	-36.9	0.00295	2.2	
		41	98.7	-93.3	0.00354	17.3	
		61	119.0	-131.3	0.00344	24.3	
	22	21	82.4	-7.1	0.00298	10.1	P_{center} = 9.21 psi
		41	160.3	-68.1	0.00268	34.4	
		61	258.8	-147.8	0.00275	91.9	
	32	21	103.2	50.8	0.00326	17.4	
		41	231.0	59.2	0.00303	80.9	
		61	294.5	156.6	0.00287	124.7	

Table D-II. Flow Parameters Predicted by RIPPLE Code-Model 40 (Continued)

Time msec	Cell No. x	Cell No. y	Air Speed ft/sec	Angle of Flow degrees	Density slugs/ft^3	Dynamic Pressure lb/ft^2	Remarks
9.00	12	21	38.8	-51.7	0.00292	2.2	
		41	95.6	-95.7	0.00359	16.4	
		61	187.4	-131.9	0.00376	66.0	
	22	21	61.3	-14.4	0.00294	5.5	P_{center} = 5.73 psi
		41	153.2	-67.0	0.00266	31.2	
		61	326.5	-140.1	0.00260	138.6	
	32	21	62.6	74.4	0.00333	6.5	
		41	235.5	60.3	0.00298	82.7	
		61	263.8	156.0	0.00306	106.5	
9.41	12	21	39.3	-49.6	0.00296	2.3	
		41	121.5	-89.1	0.00372	27.4	
		61	181.5	-122.3	0.00401	66.1	
	22	21	39.3	-33.2	0.00298	2.3	P_{center} = 6.21 psi
		41	163.7	-63.6	0.00264	35.5	
		61	326.8	-134.2	0.00250	133.4	
	32	21	48.3	83.0	0.00343	4.0	
		41	236.0	57.3	0.00287	80.0	
		61	220.4	149.9	0.00318	77.3	
11.66	12	21	49.8	-45.9	0.00312	3.9	
		41	134.0	-70.0	0.00379	34.0	
		61	206.6	-98.7	0.00390	83.3	
	22	21	75.7	-25.0	0.00318	9.1	P_{center} = 8.75 psi
		41	159.8	-45.1	0.00299	38.1	
		61	237.7	-99.4	0.00270	76.2	
	32	21	78.6	2.3	0.00378	11.7	
		41	155.1	49.0	0.00299	35.9	
		61	188.8	101.2	0.00313	55.8	

Table D-II. Flow Parameters Predicted by RIPPLE Code-Model 40 (Continued)

Time msec	Cell No. x	Cell No. y	Air Speed ft/sec	Angle of Flow degrees	Density slugs/ft^3	Dynamic Pressure lb/ft^2	Remarks
12.06	12	21	53.1	-70.6	0.00316	4.5	
		41	105.8	-68.6	0.00383	21.4	
		61	209.2	-102.3	0.00387	84.8	
	22	21	58.9	-40.9	0.00318	5.5	P_{center} = 9.25 psi
		41	140.2	-36.7	0.00304	29.9	
		61	198.7	-101.2	0.00281	55.4	
	32	21	52.5	26.6	0.00371	5.1	
		41	161.7	49.8	0.00303	39.7	
		61	205.7	101.6	0.00312	66.0	

APPENDIX E

FREDICTION OF VELOCITY FIELDS-MODEL 42

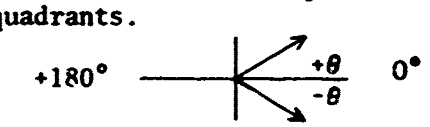
TABLE E-I. Input Parameters for RIPPLE Code Predictions-Model 42

Input shock pressure, 10 psi
Shock density, 0.003349 slugs/ft^3
Shock particle speed, 436.4 ft/sec
Shock temperature, 159.5°F
Shock sound speed, 1219.3 ft/sec
Ambient pressure, 14.7 psi
Ambient temperature, 72°F
Ambient sound speed, 1129.9 ft/sec
Ambient density of air, 0.002321 slug/ft^3
Ambient air speed, 0.0 ft/sec

Notes-1. Model 42 was assumed to be two dimensional for RIPPLE predictions. Also, stairway door opening was changed to 6 inches, instead of 5 inches, for code use.

2. Constant coefficient of drag assumed to be 0.5 for cylinders.

3. Angle of flow is positive in upper quadrants and negative in lower quadrants.



4. Time equals zero at exit of second (stairway) opening.

COMPUTATIONAL GRID

Number of columns = 45

I	DELTA X (ft)	X (ft)
1	11.495240000	11.495240000
2	4.929290000	16.424530000
3	2.113734000	18.538264000
4	.906393000	19.444657000
5	.388671500	19.333328500
6	.166666700	19.999995200
7	.166666700	20.166661900
8	.166666700	20.333328600
9	.166666700	20.499995300
10	.166666700	20.666662000
11	.166666700	20.833328700
12	.166666700	20.999995400
13	.166666700	21.166662100
14	.166666700	21.333328800
15	.166666700	21.499995500
16	.166666700	21.666662200
17	.166666700	21.833328900
18	.166666700	21.999995600
19	.166666700	22.166662300
20	.166666700	22.333329000
21	.166666700	22.499995700
22	.166666700	22.666662400
23	.166666700	22.833329100
24	.166666700	22.999995800
25	.166666700	23.166662500
26	.166666700	23.333329200
27	.166666700	23.499995900
28	.166666700	23.666662600
29	.166666700	23.833329300
30	.166666700	23.999996000
31	.166666700	24.166662700
32	.166666700	24.333329400
33	.166666700	24.499996100
34	.166666700	24.666662800
35	.166666700	24.833329500
36	.166666700	24.999996200
37	.166666700	25.166662900
38	.166666700	25.333329600
39	.166666700	25.499996300
40	.166666700	25.666663000
41	.166666700	25.833329700
42	.498822500	26.332152200
43	1.492944000	27.825096200
44	4.468284000	32.293380200
45	13.373280000	45.666660200

Table E-1 (Continued)

Number of rows = 83

J	DELTA Y (ft)	Y (ft)
1	1.520871000	1.520871000
2	1.108957000	2.629828000
3	.808606100	3.438434100
4	.589602600	4.028036700
5	.429914100	4.457950800
6	.313475800	4.771426600
7	.228573800	5.000000400
8	.166666700	5.166667100
9	.166666700	5.333333800
10	.166666700	5.500000500
11	.166666700	5.666667200
12	.166666700	5.833333900
13	.166666700	6.000000600
14	.166666700	6.166667300
15	.166666700	6.333334000
16	.166666700	6.500000700
17	.166666700	6.666667400
18	.166666700	6.833334100
19	.166666700	7.000000800
20	.166666700	7.166667500
21	.166666700	7.333334200
22	.166666700	7.500000900
23	.166666700	7.666667600
24	.166666700	7.833334300
25	.166666700	8.000001000
26	.166666700	8.166667700
27	.166666700	8.333334400
28	.166666700	8.500001100
29	.166666700	8.666667800
30	.166666700	8.833334500
31	.166666700	9.000001200
32	.166666700	9.166667900
33	.166666700	9.333334600
34	.166666700	9.500001300
35	.166666700	9.666668000
36	.166666700	9.833334700
37	.166666700	10.000001400
38	.166666700	10.166668100
39	.166666700	10.333334800
40	.166666700	10.500001500

Table E-1 (Continued)

J	DELTA Y (ft)	Y (ft)
41	.166666700	10.666666200
42	.166666700	10.833334900
43	.166666700	11.000001600
44	.166666700	11.166668300
45	.166666700	11.333335000
46	.166666700	11.500001700
47	.166666700	11.666668400
48	.166666700	11.833335100
49	.166666700	12.000001800
50	.166666700	12.166668500
51	.166666700	12.333335200
52	.166666700	12.500001900
53	.166666700	12.666668600
54	.166666700	12.833335300
55	.166666700	13.000002000
56	.166666700	13.166668700
57	.166666700	13.333335400
58	.166666700	13.500002100
59	.166666700	13.666668800
60	.166666700	13.833335500
61	.166666700	14.000002200
62	.166666700	14.166668900
63	.166666700	14.333335600
64	.166666700	14.500002300
65	.166666700	14.666669000
66	.166666700	14.833335700
67	.166666700	15.000002400
68	.166666700	15.166669100
69	.166666700	15.333335800
70	.166666700	15.500002500
71	.166666700	15.666669200
72	.166666700	15.833335900
73	.166666700	16.000002600
74	.166666700	16.166669300
75	.166666700	16.333336000
76	.166666700	16.500002700
77	.166666700	16.666669400
78	.166665700	16.833336100
79	.166666700	17.000002800
80	.166666700	17.166669500
81	.166666700	17.333336200
82	.166666700	17.500002900
83	.166666700	17.666669600

Table E-1 (Continued

Table E-II Flow Parameters for RIPPLE Code Predictions - Model 42

Time msec	Cell No. x	Cell No. y	Air Speed, μx ft/sec	Air Speed, μy ft/sec
1.10	8	24	-19.5	55.8
		36	- .1	.1
		48	.0	.0
		66	.0	.0
	13	78	.0	.0
	15	24	-47.7	59.5
		36	- 1.1	3.8
		48	.0	.0
		66	.0	.0
	18	24	1.8	122.4
		36	.0	6.4
		48	.0	.0
		66	.0	.0
	24	24	51.7	40.0
		36	.7	1.1
		48	.0	.0
		66	.0	.0
	32	24	7.4	3.7
		36	.0	.0
		48	.0	.0
		66	.0	.0
	36	18	4.8	.6
		78	.0	.0
2.07	8	24	23.4	158.6
		36	-6.2	21.2
		48	.0	.0
		66	.0	.0
	13	78	.0	.0

Table E-II (Continued)

Time msec	Cell No. x	Cell No. y	Air Speed, μx ft/sec	Air Speed, μy ft/sec
	15	24	-12.8	88.6
		36	-12.8	31.6
		48	- .1	.3
		66	.0	.0
	18	24	35.5	137.9
		36	.2	60.8
		48	.0	.4
		66	.0	.0
	24	24	55.2	32.5
		36	14.7	31.2
		48	.1	.1
		66	.0	.0
	32	24	39.4	14.2
		36	2.8	2.9
		48	.0	.0
		66	.0	.0
	36	18	33.0	4.2
		78	.0	.0
4.03	8	24	47.0	198.6
		36	10.3	117.9
		48	.9	55.6
		66	.0	.0
	13	78	.0	.0
	15	24	49.4	65.9
		36	49.8	119.1
		48	- 2.1	26.1
		66	.0	.0
	18	24	95.9	255.4
		36	62.3	109.7
		48	1.1	47.6
		66	.0	.0

Table E-II (Continued)

Time msec	Cell No. x	y	Air Speed, μx ft/sec	Air Speed, μy ft/sec
	24	24	145.9	27.3
		36	45.4	55.1
		48	7.5	31.8
		66	.0	.0
	32	24	46.1	16.1
		36	25.6	23.8
		48	10.1	14.8
		66	.0	.0
	36	18	16.5	6.0
		78	.0	.0
6.96	8	24	83.6	338.0
		36	17.0	141.5
		48	5.1	93.0
		66	3.9	65.2
	13	78	- .1	4.4
	15	24	94.5	34.6
		36	47.0	100.6
		42	29.0	86.9
		66	11.5	54.1
	18	24	116.9	225.6
		36	48.7	116.7
		48	37.3	85.8
		66	13.5	55.4
	24	24	149.3	40.3
		36	74.5	79.3
		48	46.3	75.7
		66	9.6	33.9

Table E-II (Continued)

Time msec	Cell No. x	y	Air Speed, μx ft/sec	Air Speed, μy ft/sec
	32	24	74.2	13.0
		36	55.7	51.4
		48	45.9	74.2
		66	8.2	21.9
	36	18	39.9	- .2
		78	.3	.8
8.89	8	24	83.3	439.8
		36	24.9	181.6
		48	5.3	105.7
		66	3.0	74.6
	13	78	8.3	53.7
	15	24	62.7	4.2
		36	42.7	99.3
		48	20.8	87.9
		66	16.3	72.6
	18	24	147.1	219.5
		36	36.2	121.1
		48	23.4	96.8
		66	20.6	73.6
	24	24	148.9	46.4
		36	72.7	89.4
		48	35.4	84.2
		66	24.3	74.3
	32	24	39.2	4.8
		36	28.1	55.1
		48	18.1	73.7
		66		-5.7
	36	18	.7	
		78	4.4	24.6

Table E-II (Continued)

Time msec	x	y	Air Speed, μx ft/sec	Air Speed, μy ft/sec
10.75	8	24	76.9	515.3
		36	44.5	232.3
		48	7.0	130.4
		66	.6	69.2
	13	78	13.1	8.3
	15	24	-5.7	-55.4
		36	57.4	91.5
		48	20.0	107.5
		66	3.7	73.1
	18	24	149.2	274.6
		36	35.8	107.6
		48	15.4	104.8
		66	7.8	70.8
	24	24	115.8	26.8
		36	49.8	93.4
		48	12.9	93.5
		66	11.3	71.8
	32	24	33.9	-9.9
		36	23.1	51.4
		48	6.7	77.1
		66	-5.0	82.7
	36	18	-7.6	-14.7
		78	19.2	48.0
12.55	8	24	47.8	545.1
		36	61.9	293.9
		48	8.0	147.6
		66	3.9	45.3
	13	78	.4	14.6

Table E-II (Continued)

Time msec	Cell No. x	Cell No. y	Air Speed, μx ft/sec	Air Speed, μy ft/sec
	15	24	-57.3	-50.7
		36	55.9	77.6
		48	17.6	113.6
		66	4.2	46.4
	18	24	116.1	340.0
		36	52.5	80.4
		48	14.4	105.3
		66	.1	45.8
	24	24	94.0	-4.2
		36	62.7	89.5
		48	21.0	93.9
		66	-1.1	43.0
	32	24	30.2	-21.1
		36	28.8	39.2
		48	10.2	72.5
		66	4.0	43.2
	36	18	-12.2	-18.1
		78	- 4.2	- 2.6
14.30	8	24	5.8	516.5
		36	80.6	360.1
		48	18.6	142.1
		66	-1.4	55.9
	13	78	-11.9	22.0
	15	24	-56.9	5.7
		36	73.4	37.4
		48	42.7	87.1
		66	-3.2	44.9

Table E-11 (Continued)

Time msec	Cell No. x	Cell No. y	Air Speed, μx ft/sec	Air Speed, μy ft/sec
	18	24	90.9	322.7
		36	79.3	77.6
		48	37.4	66.8
		66	.5	37.1
		24	52.4	-22.3
		36	75.5	72.9
		48	38.1	65.8
		66	5.8	26.6
		24	28.5	-33.4
		36	39.4	26.4
		48	25.3	49.1
		66	-1.9	2.9
		18	-15.0	-22.1
		78	- 8.8	2.8
15.17	8	24	-11.6	497.1
		36	83.0	383.6
		48	24.7	130.0
		66	1.7	49.7
	13	78	-15.6	12.3
	15	24	-77.2	41.7
		36	75.2	12.4
		48	60.2	61.2
		66	5.7	42.7
	18	24	84.0	309.2
		36	89.1	80.4
		48	54.6	44.4
		66	2.2	31.1
	24	24	35.2	-26.0
		36	89.7	54.8
		48	47.4	39.1
		66	-2.9	14.5

Table E-II (Continued)

Time msec	Cell No. x	y	Air Speed, μx ft/sec	Air Speed, μy ft/sec
	32	24	24.0	-37.5
		36	40.6	15.5
		48	32.1	18.0
		66	-3.1	-1.4
	36	18	-15.3	-23.0
		78	- 7.2	3.2

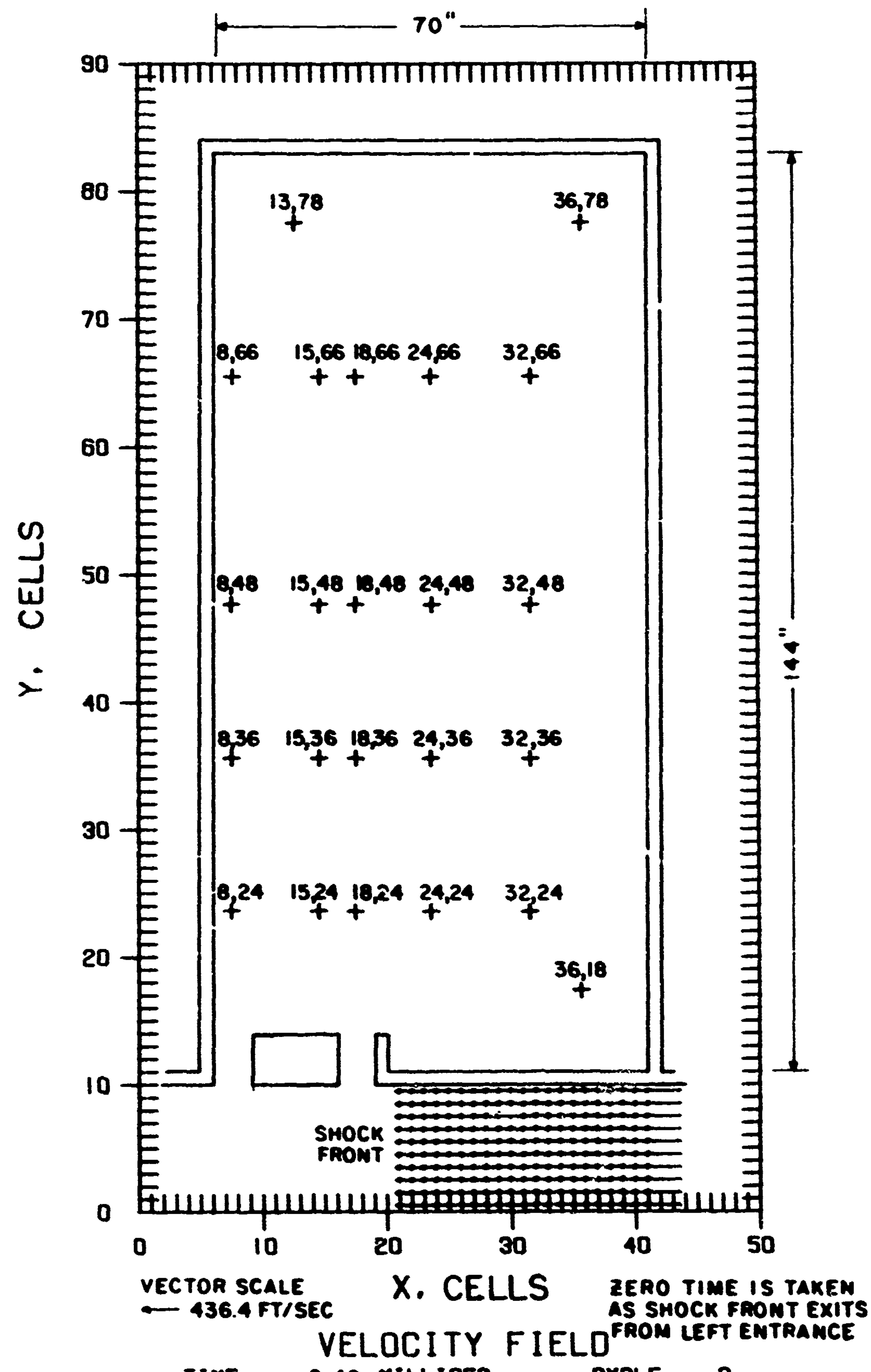


Figure E-1. Velocity Field at -2.5 milliseconds

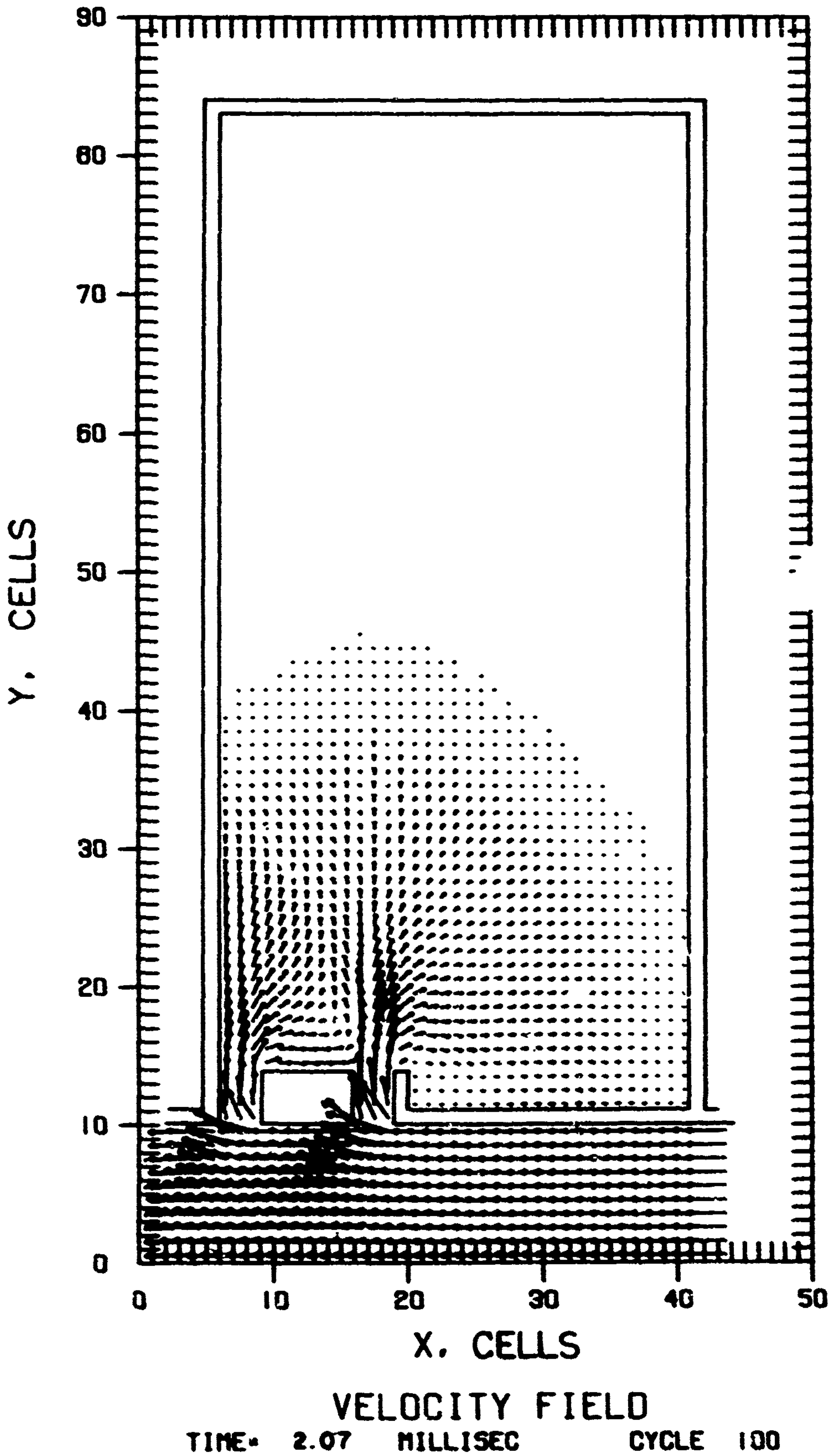


Figure E-2. Velocity Field at 2.1 milliseconds

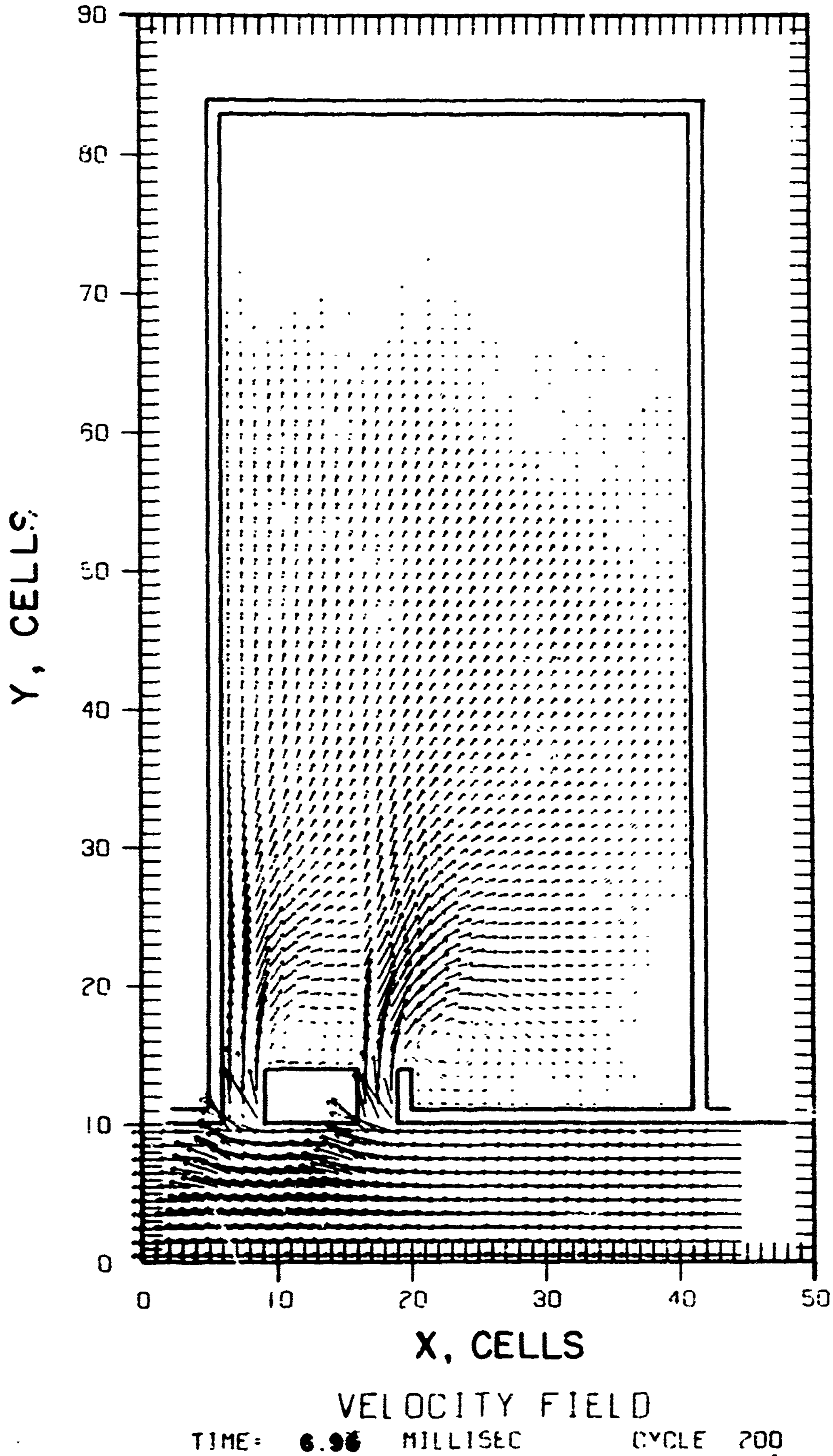


Figure E-3. Velocity Field at 7.0 milliseconds

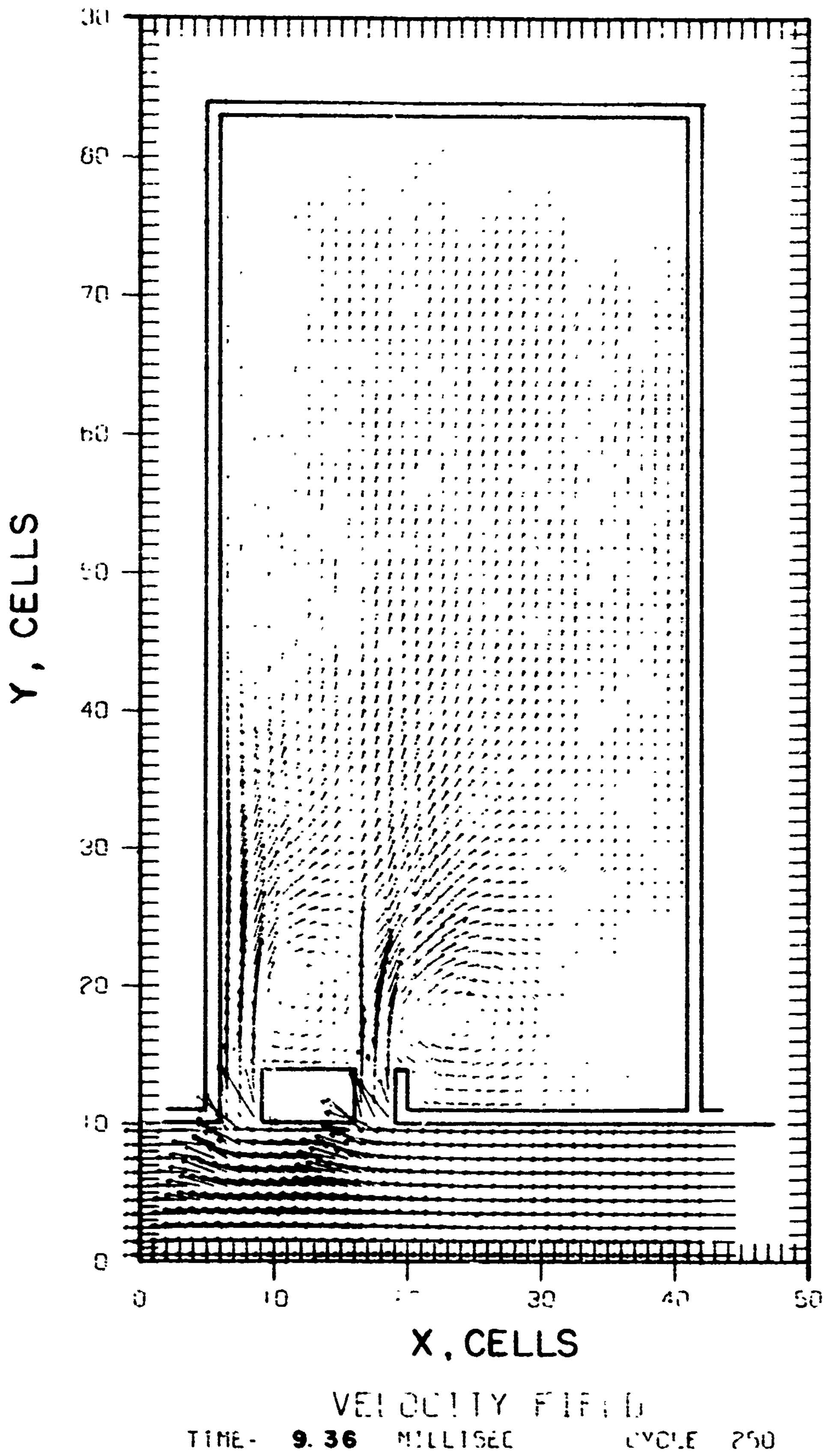


Figure E-4. Velocity Field at 9.4 milliseconds

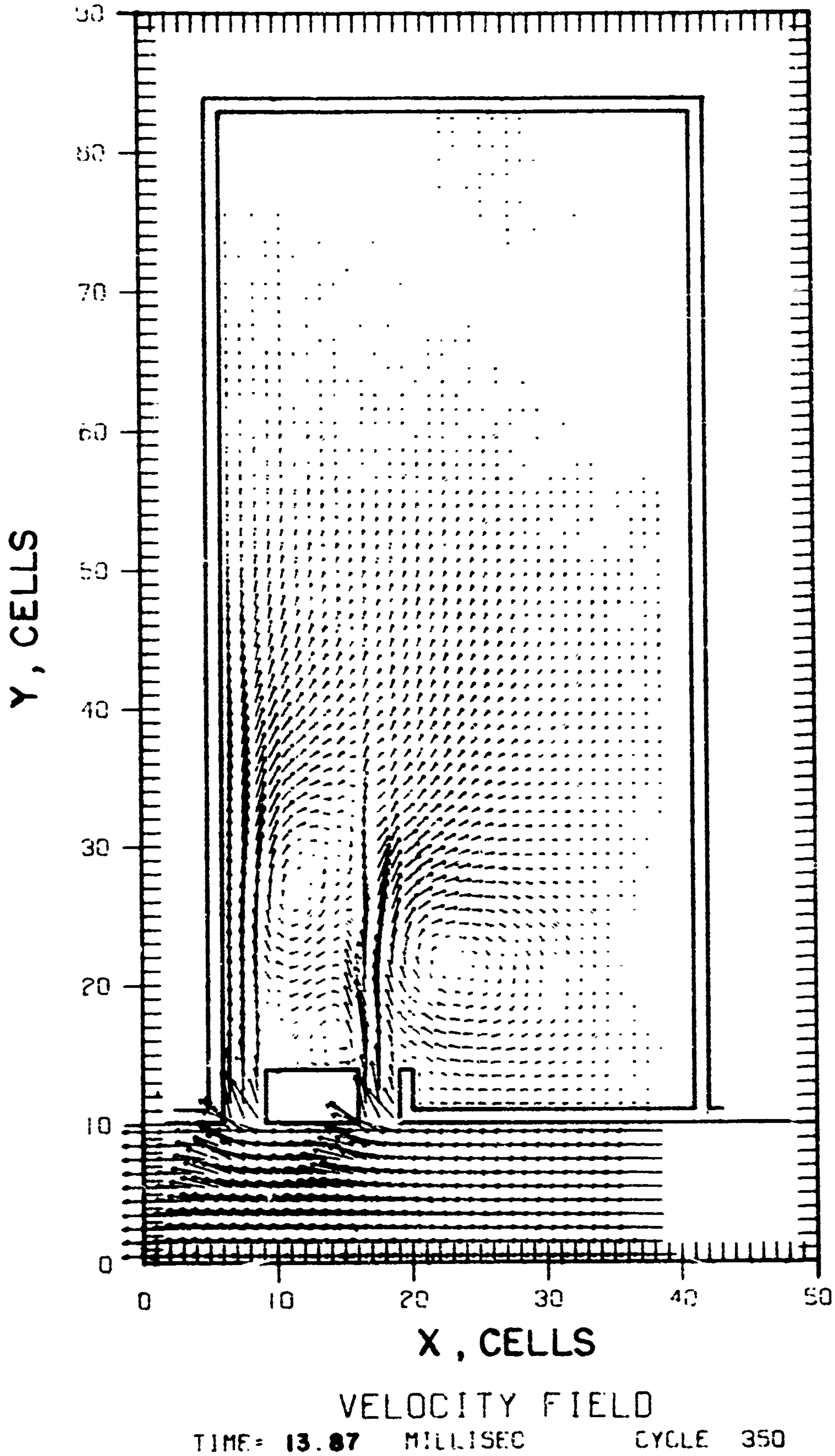


Figure E-5. Velocity Field at 13.9 milliseconds

APPENDIX F

FILL PRESSURE AND MOTION PREDICTIONS FOR CYLINDERS IN BASEMENT SHELTERS

1. FILL-PRESSURE CURVES

2. MOTION PREDICTIONS FOR CYLINDERS

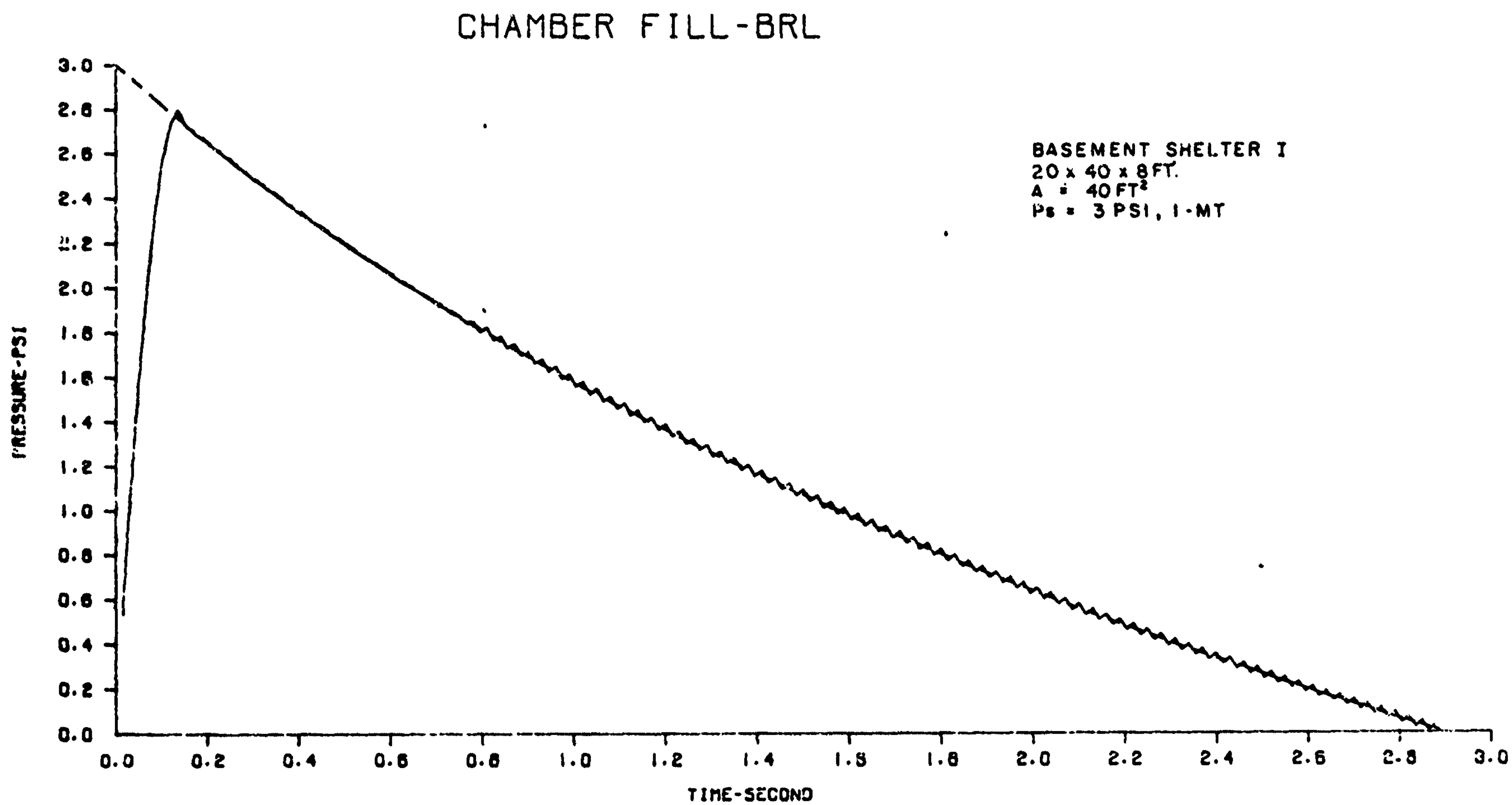


Figure F-1. Fill Prediction for Basement Shelter I

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CHAMBER FILL-BRL

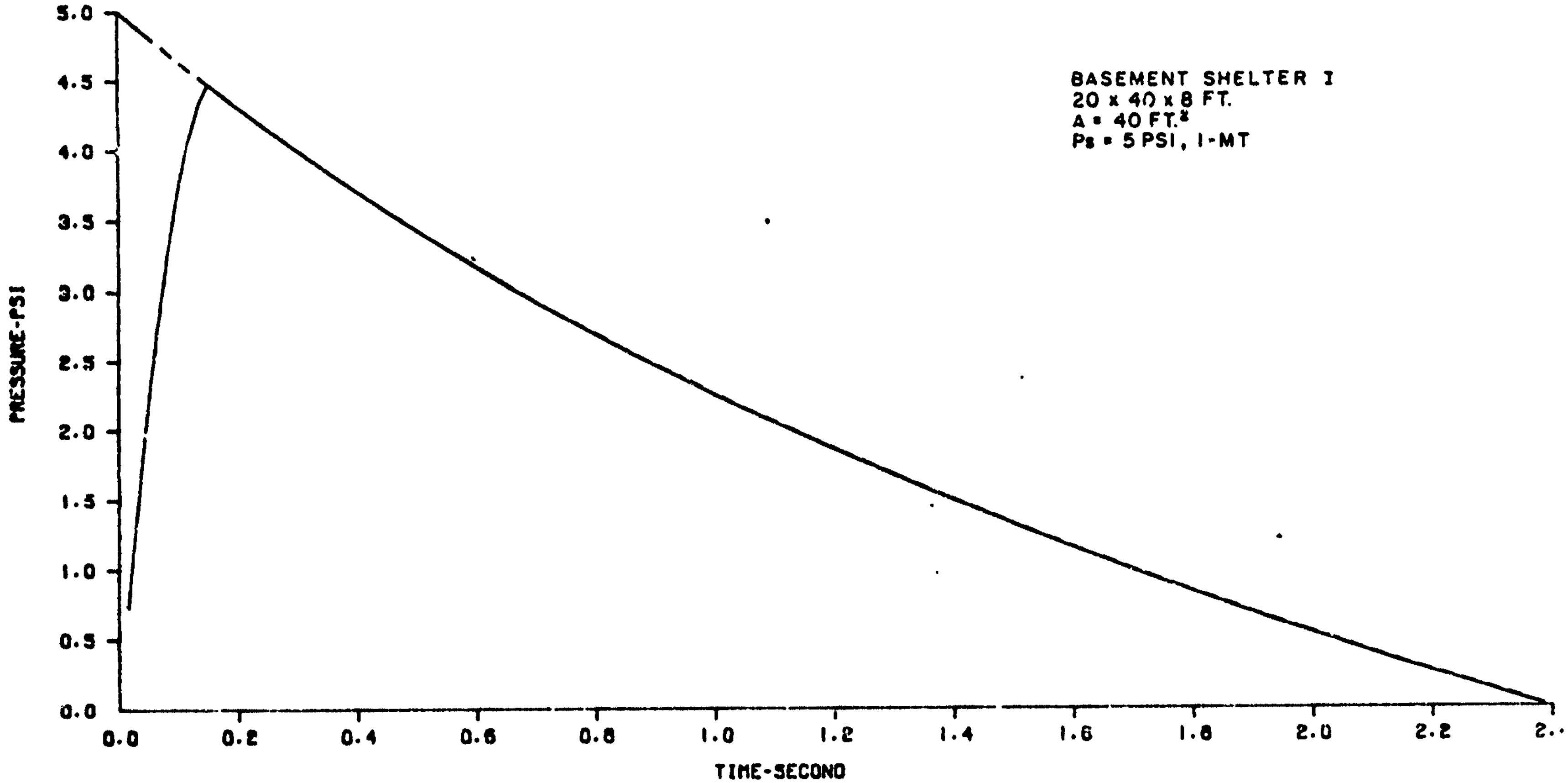

Figure F-1. Continued

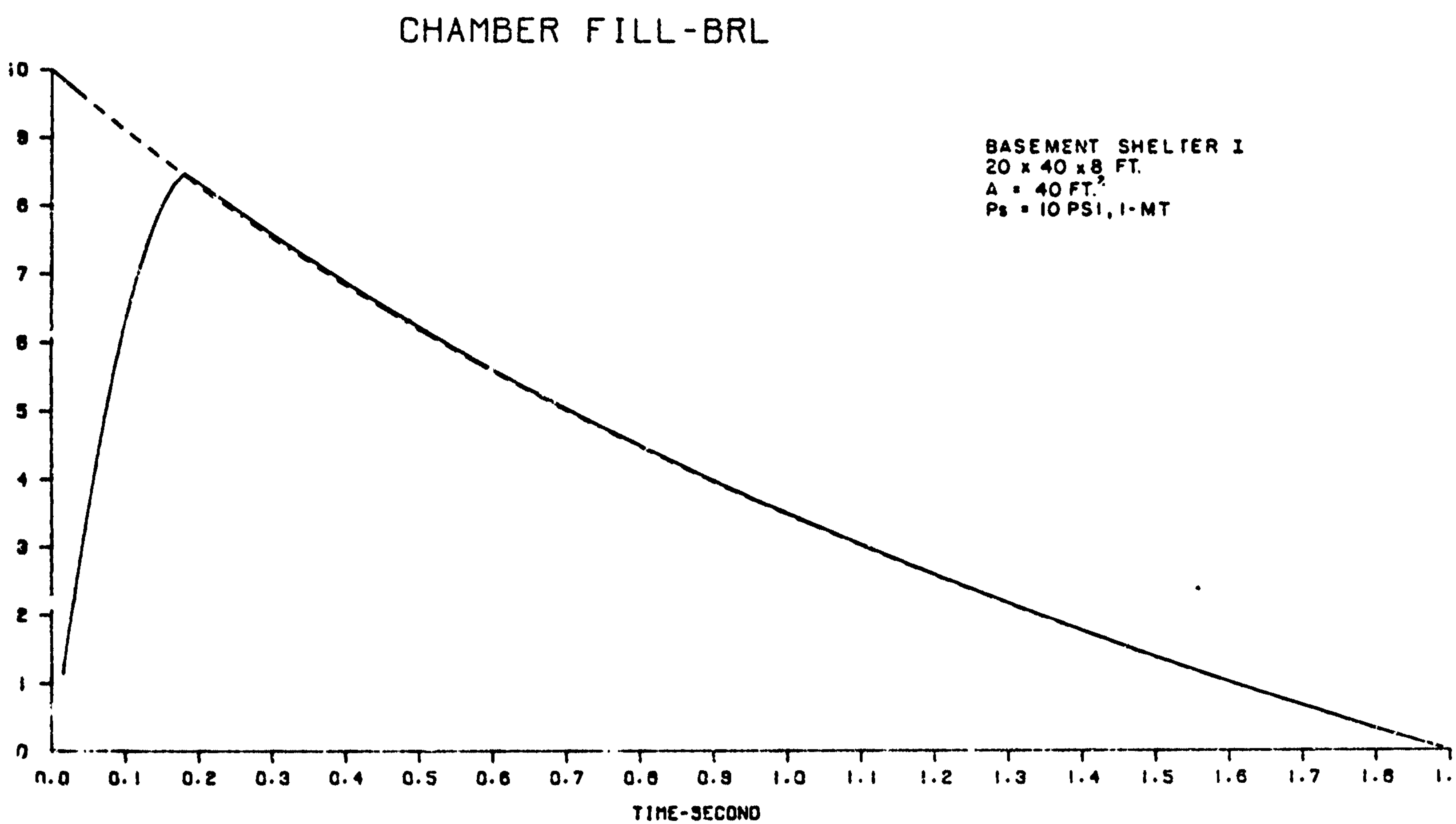

Figure F-1. Continued

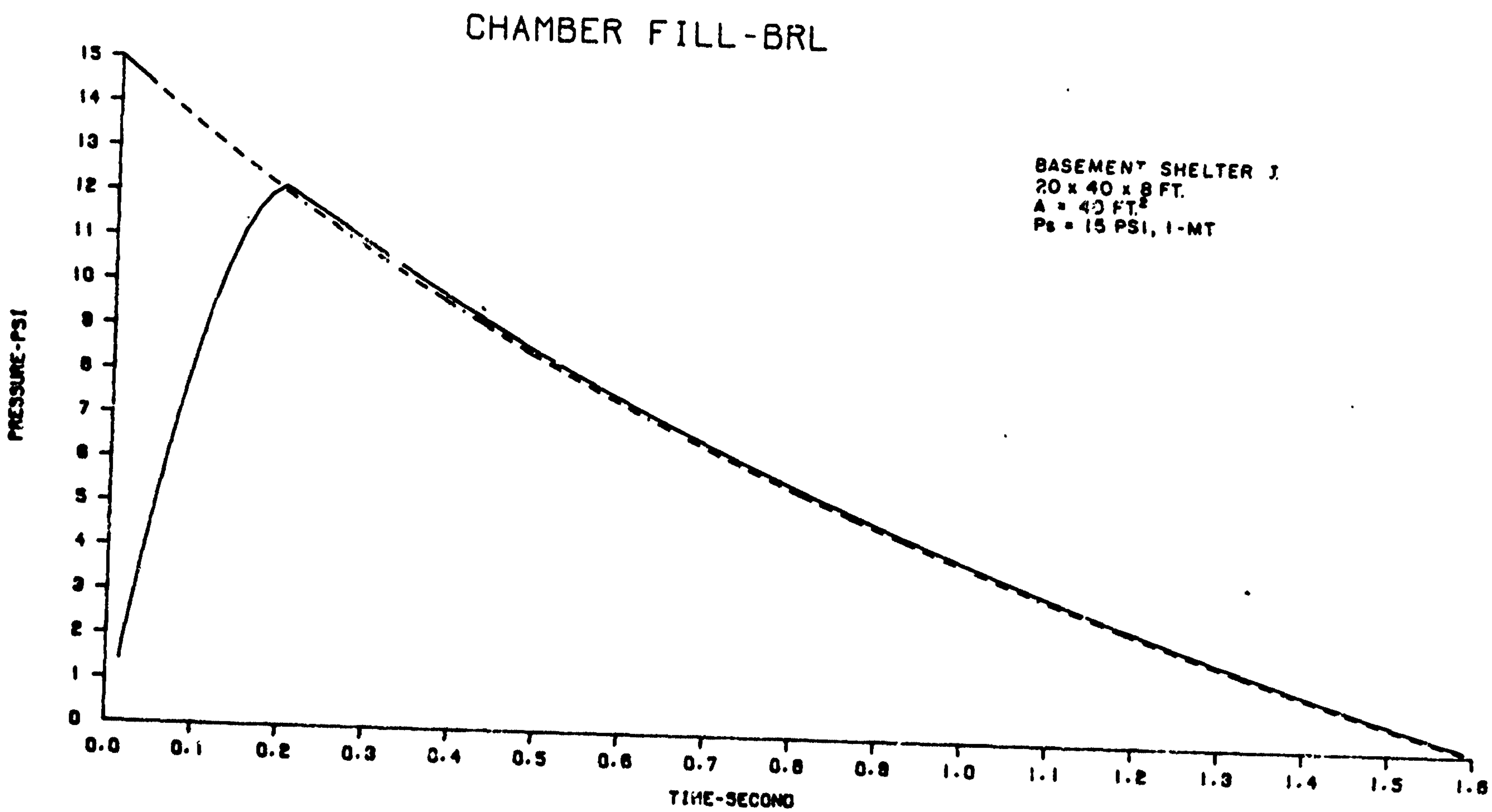

Figure F-1. Continued

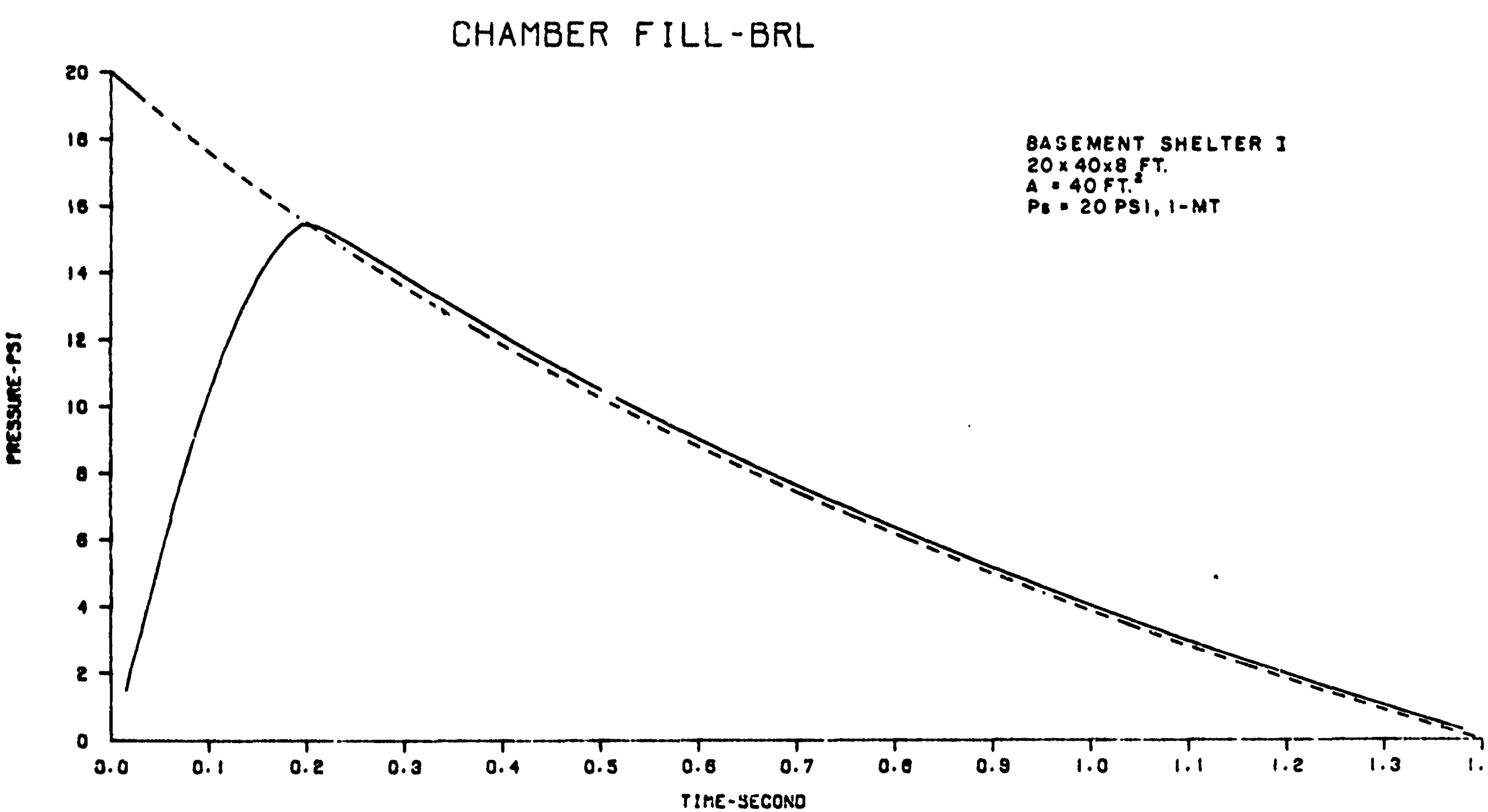

Figure F-1. Continued

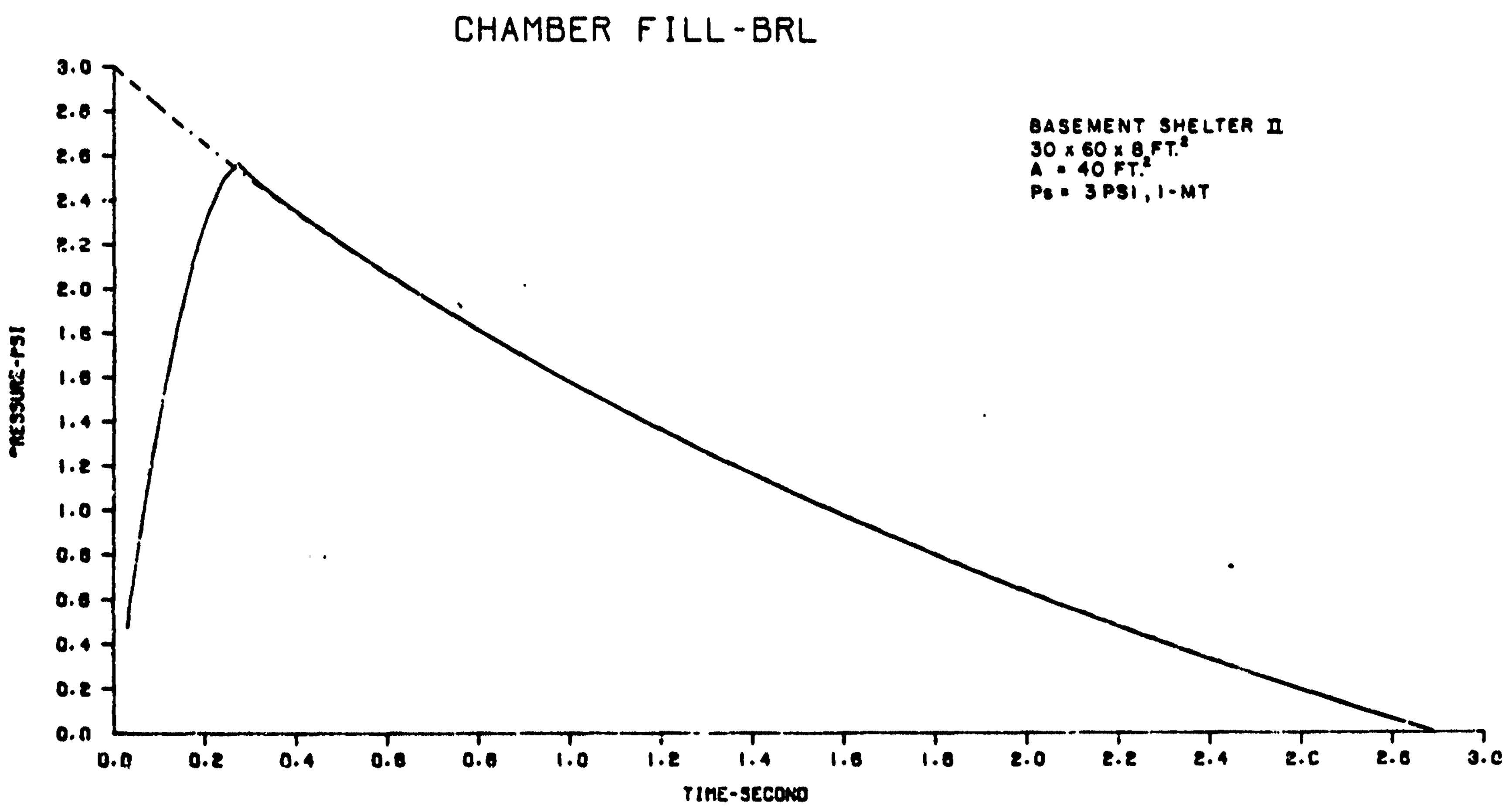

Figure F-2. Fill Prediction for Basement Shelter II

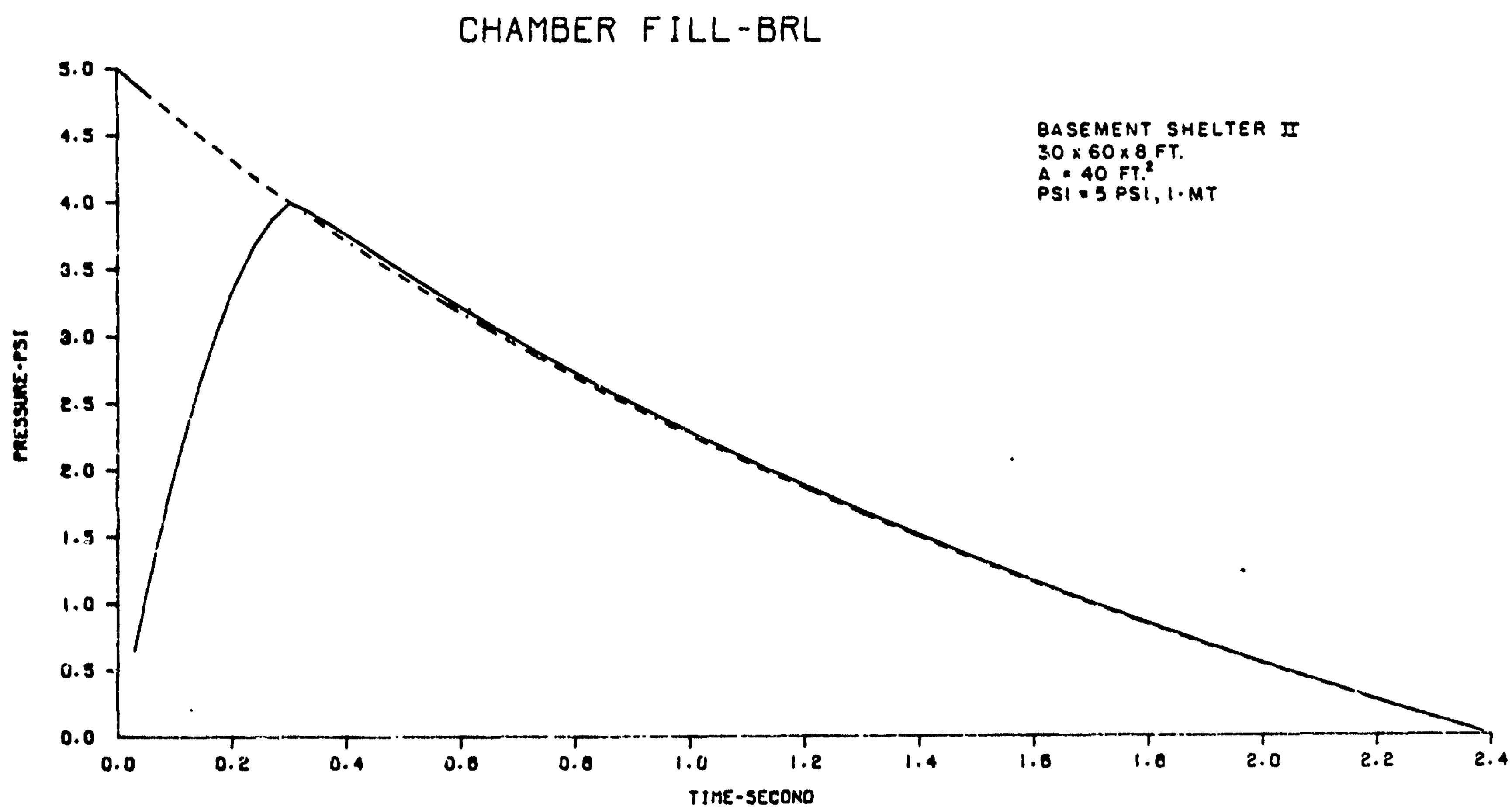

Figure F-2. Continued

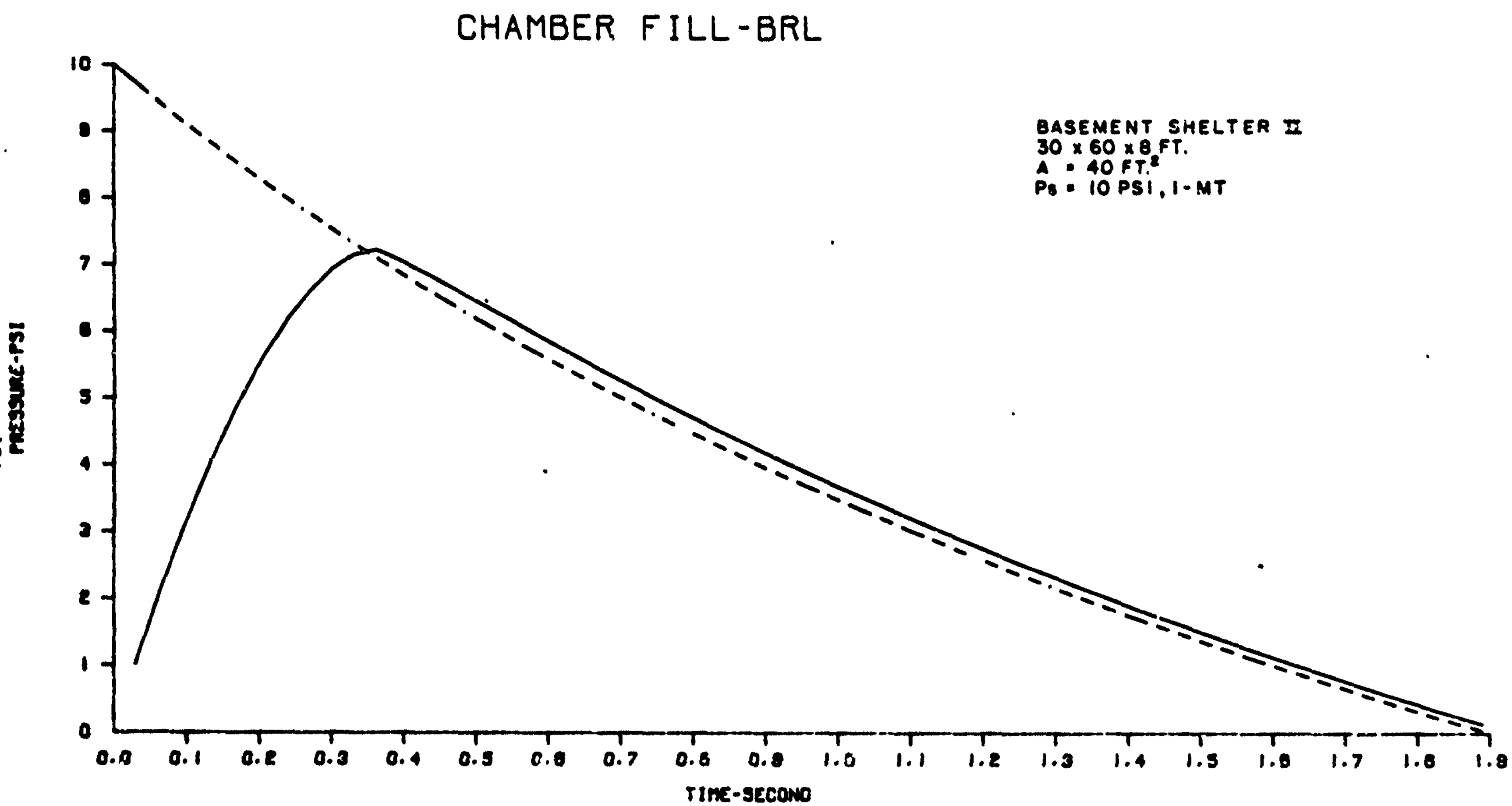

Figure F-2. Continued

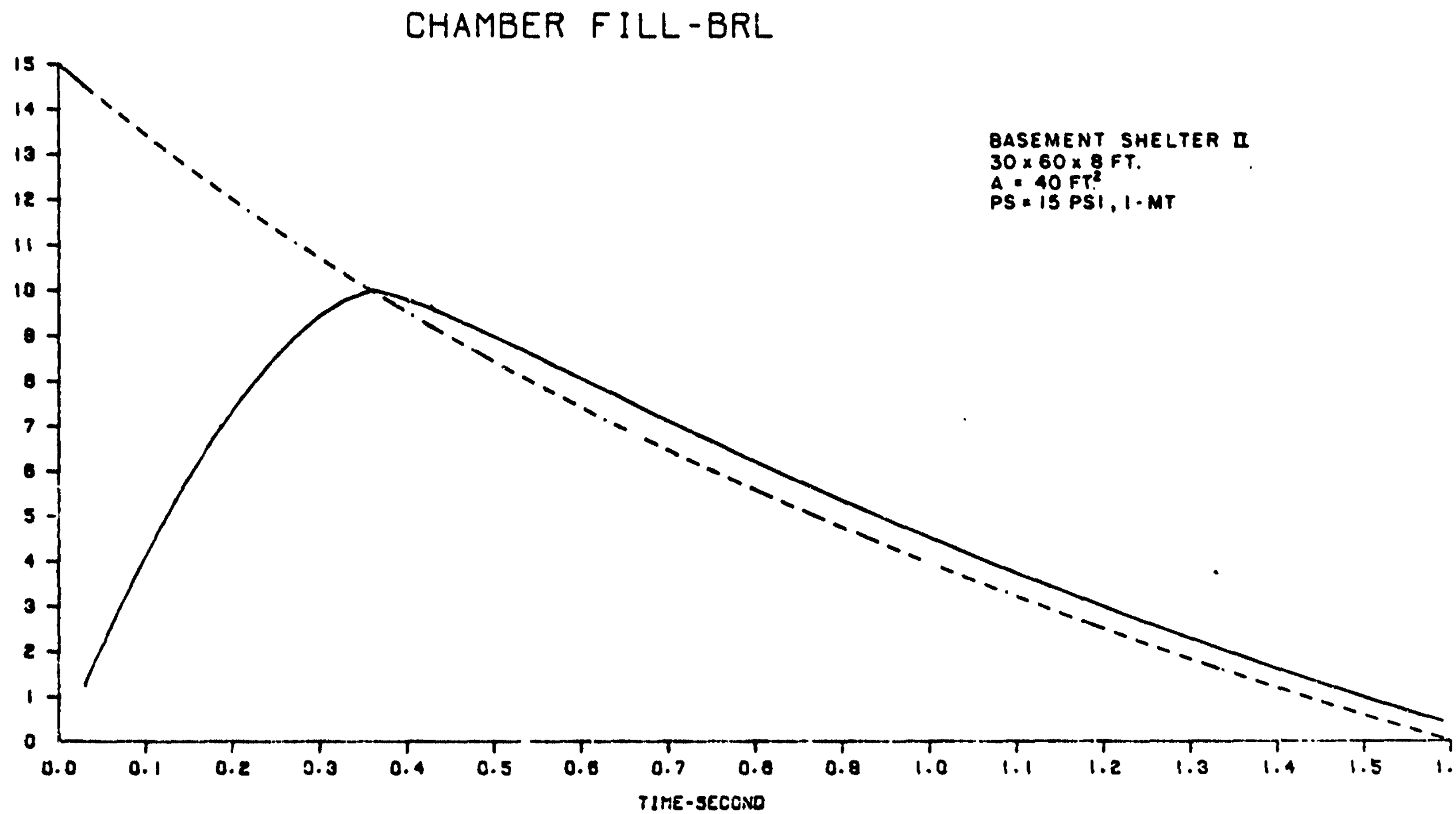

Figure F-2. Continued

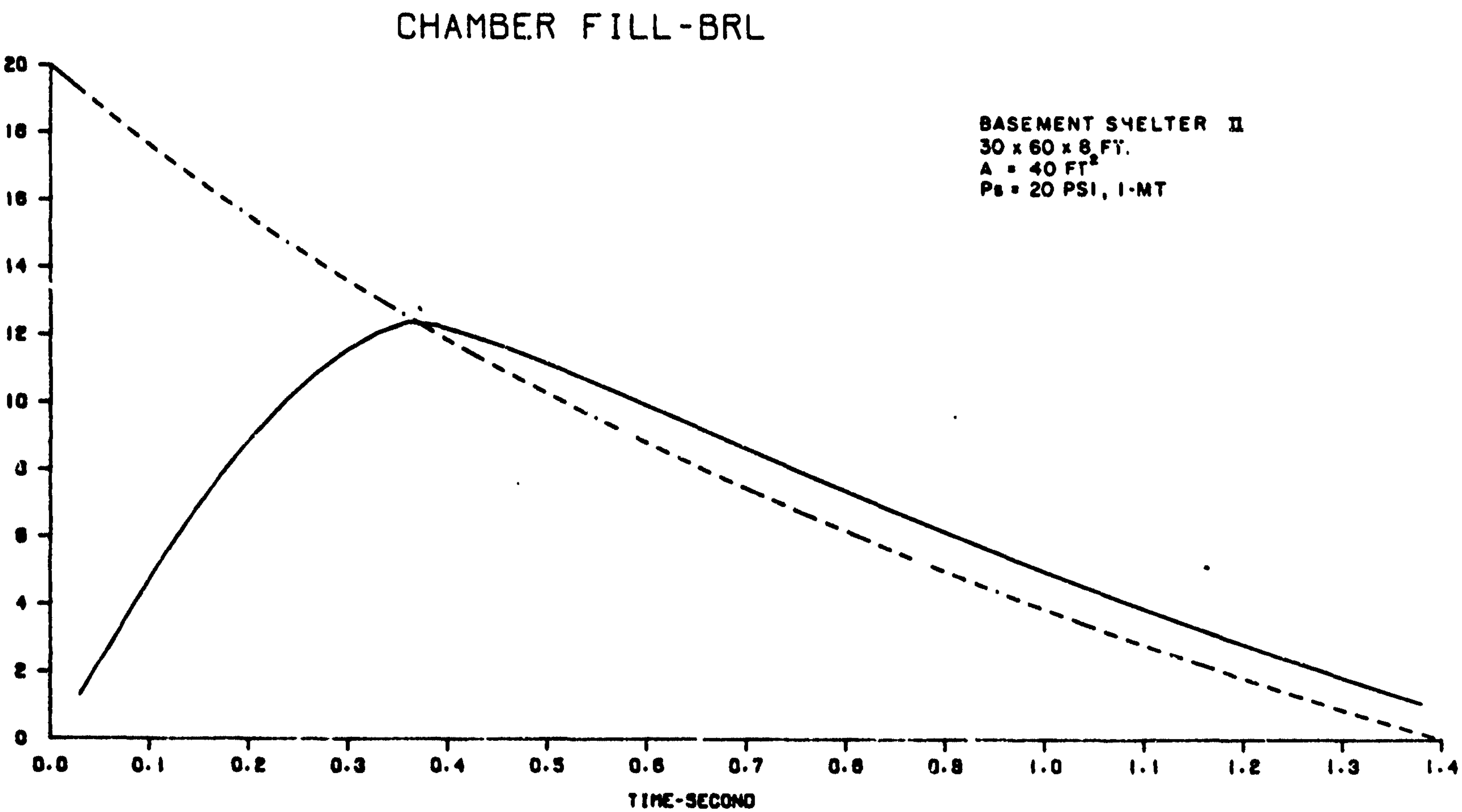

Figure F-2. Continued

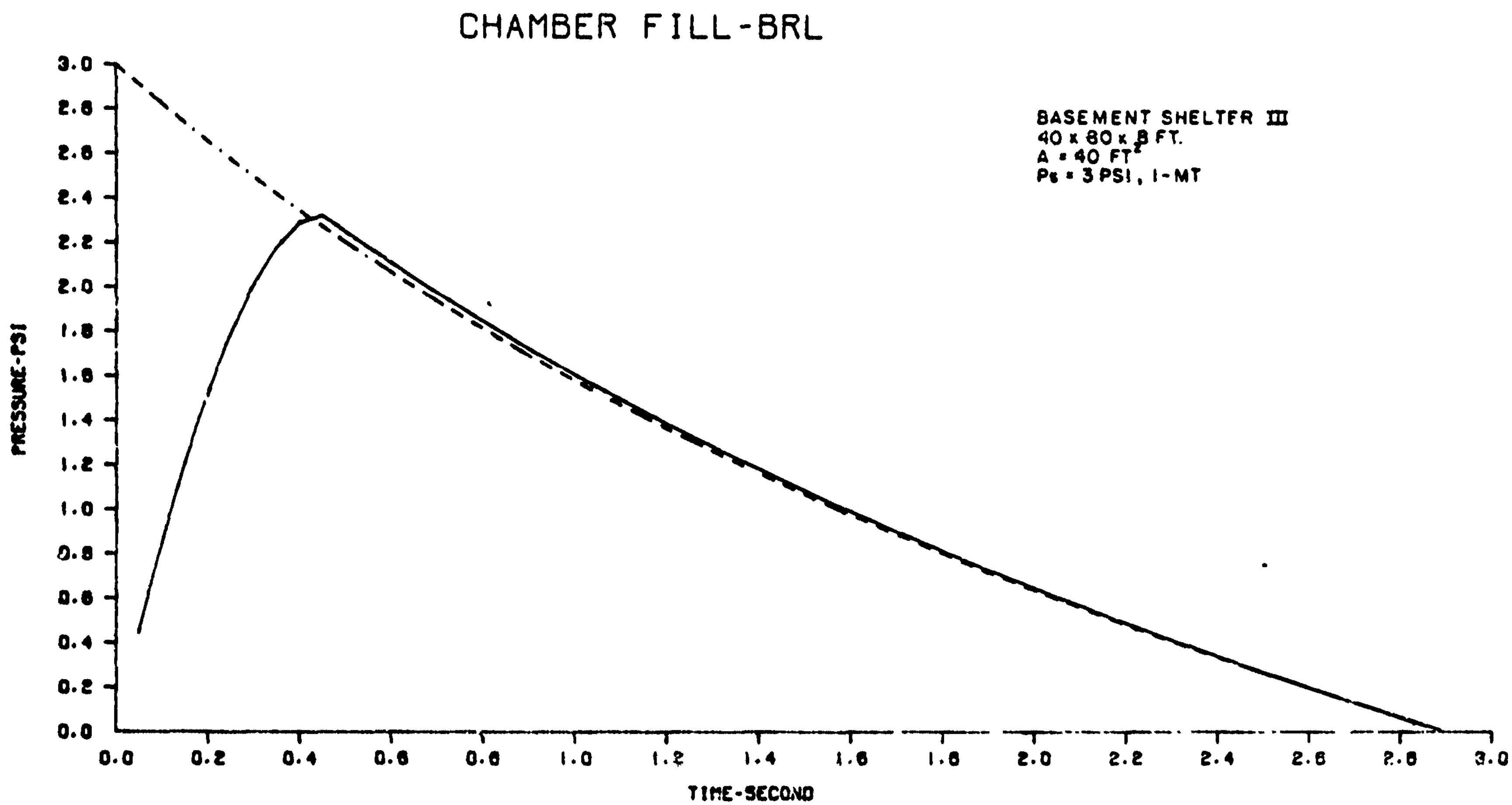

Figure F-3. Fill Prediction for Basement Shelter III

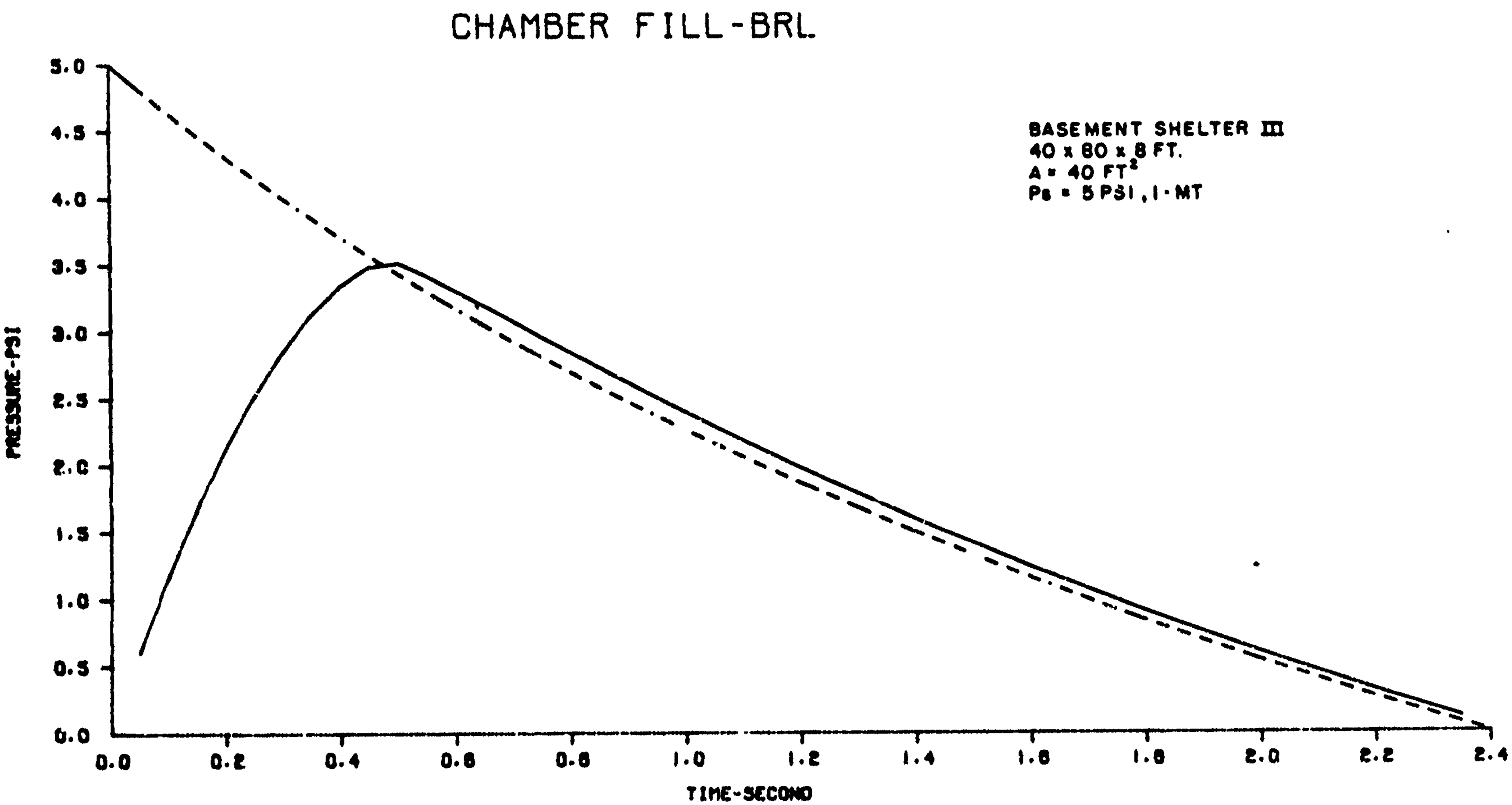

Figure F-3. Continued

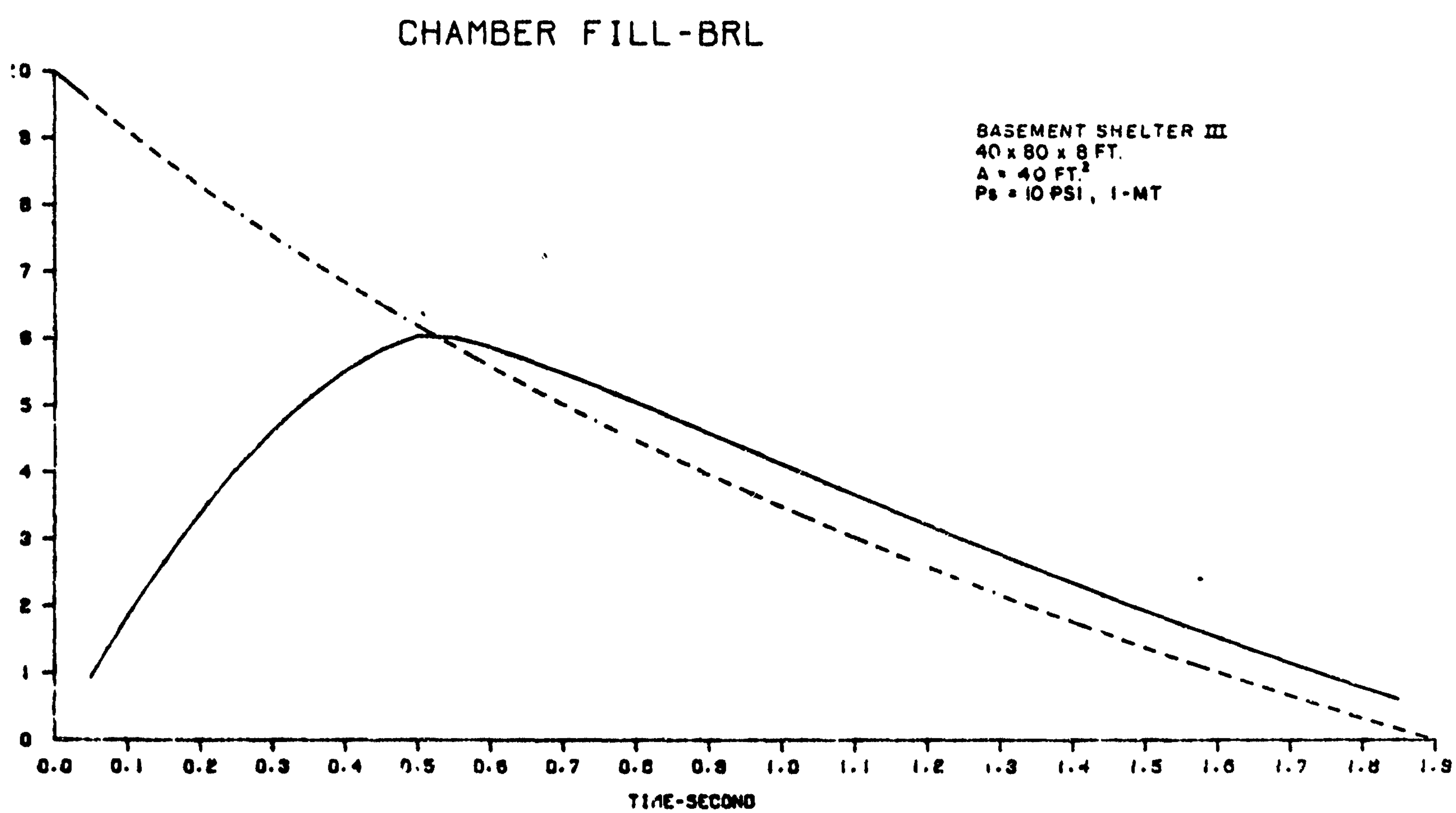

Figure F-3. Continued

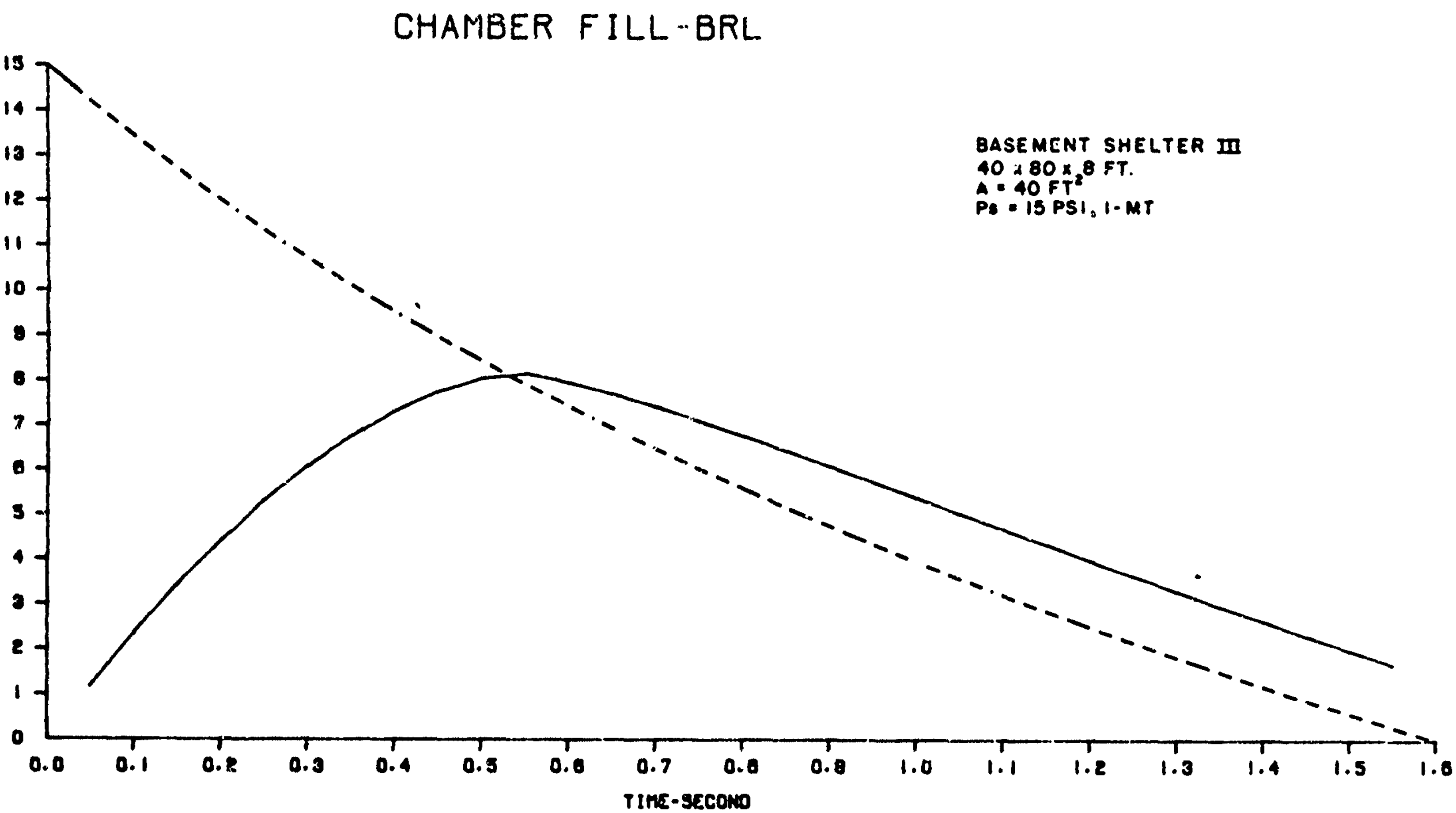

Figure F-3. Continued

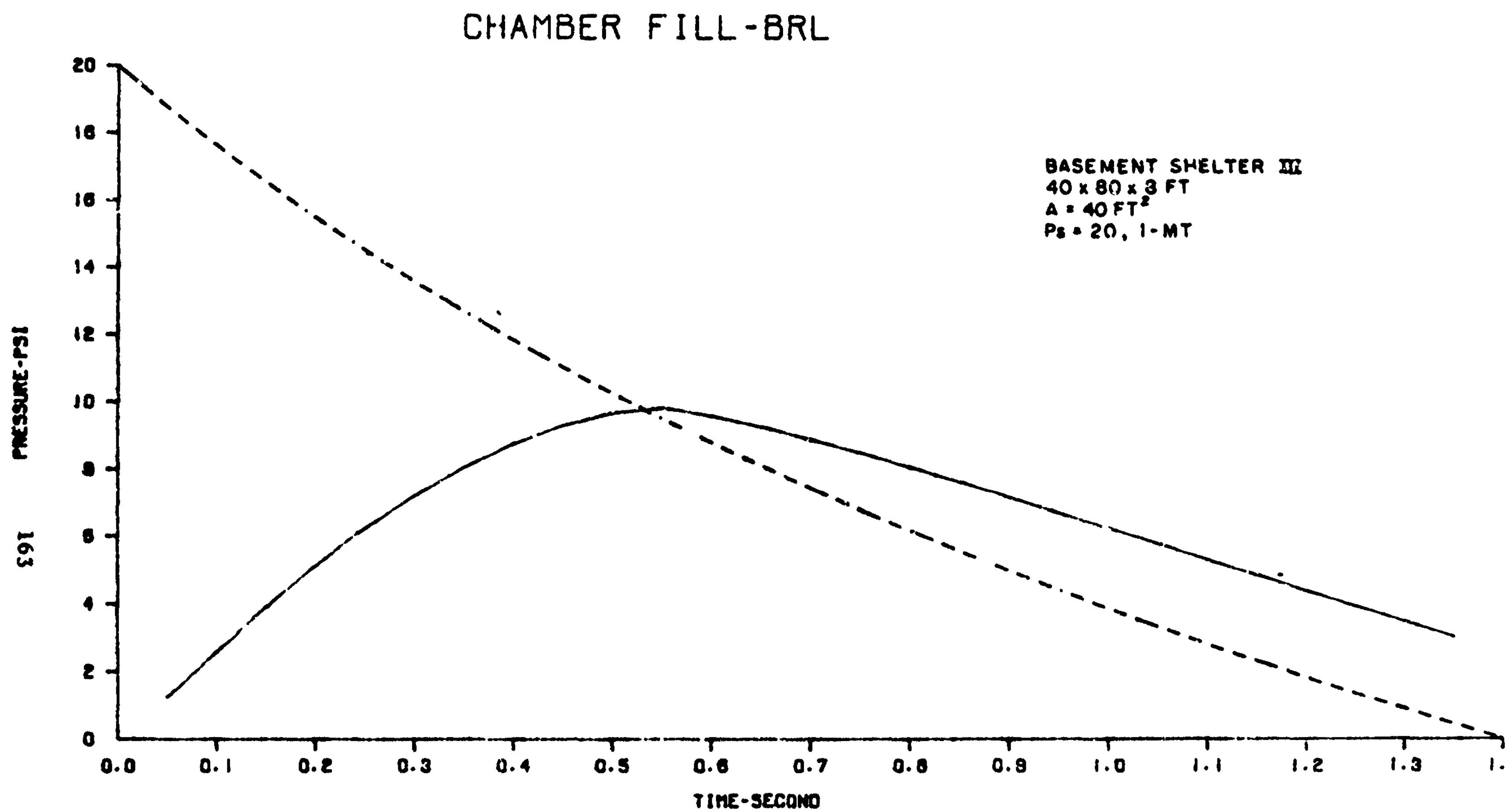

Figure F-3. Continued

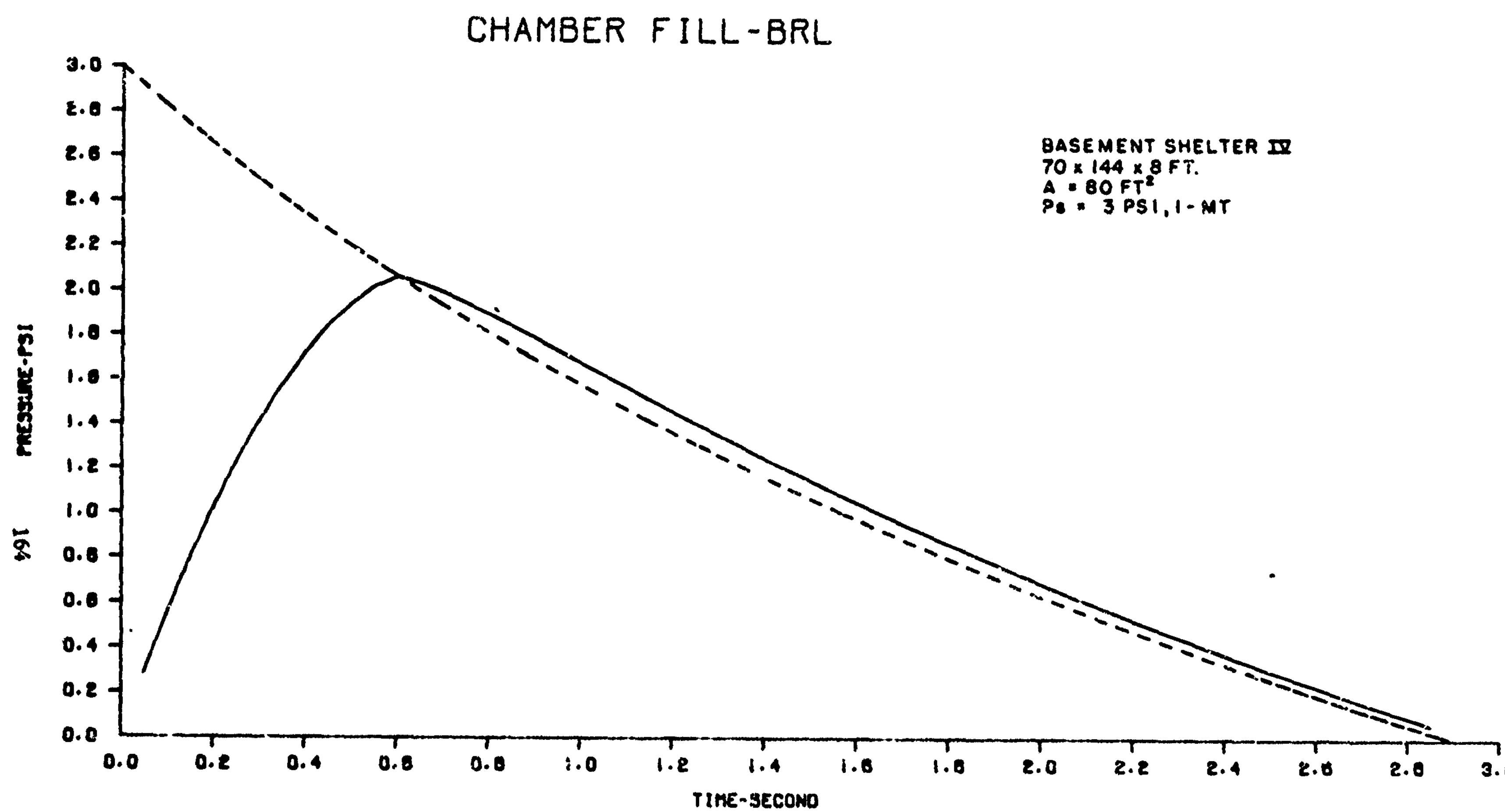

Figure F-4. Fill Prediction for Basement Shelter IV

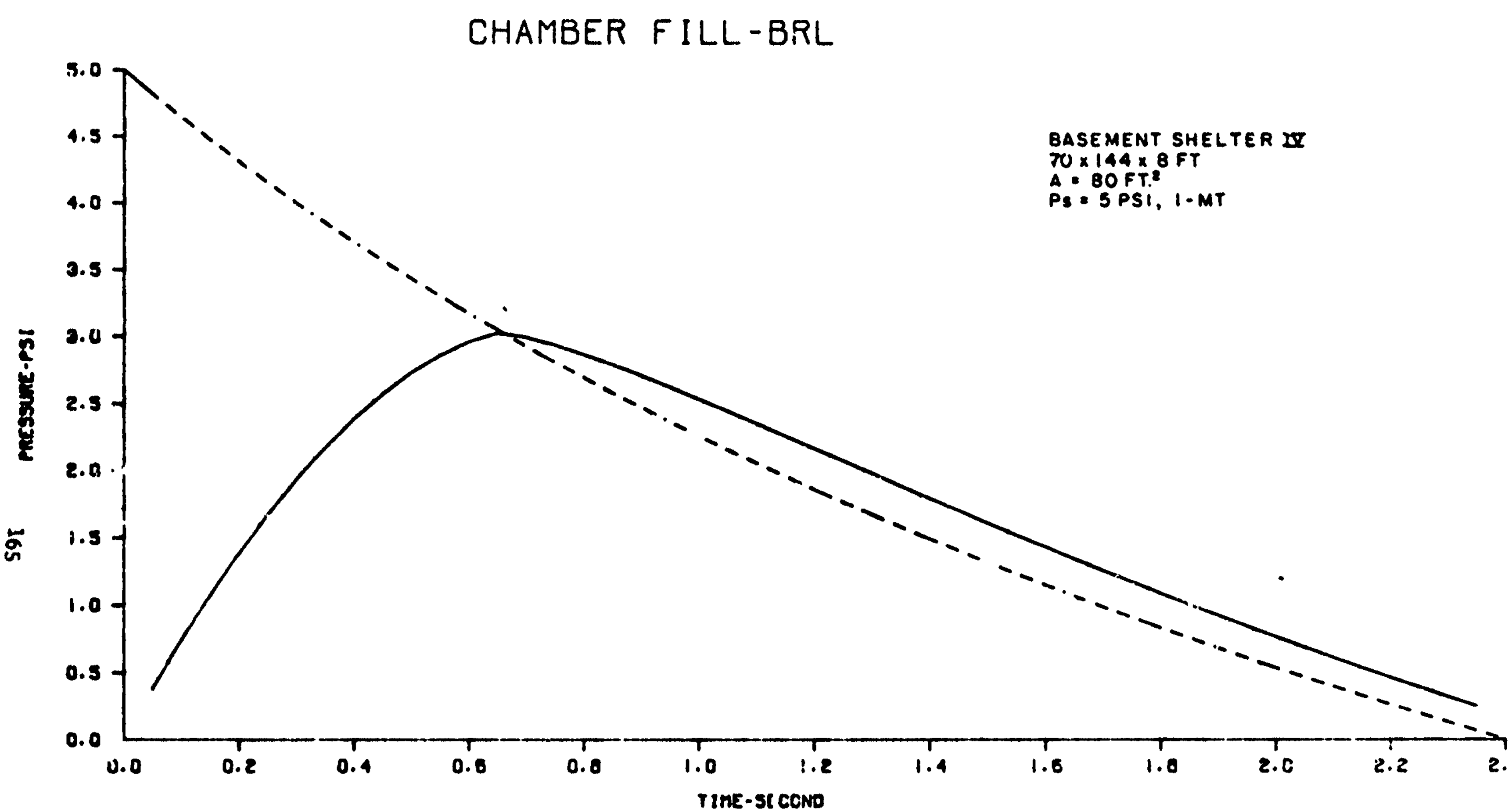

Figure F-4. Continued

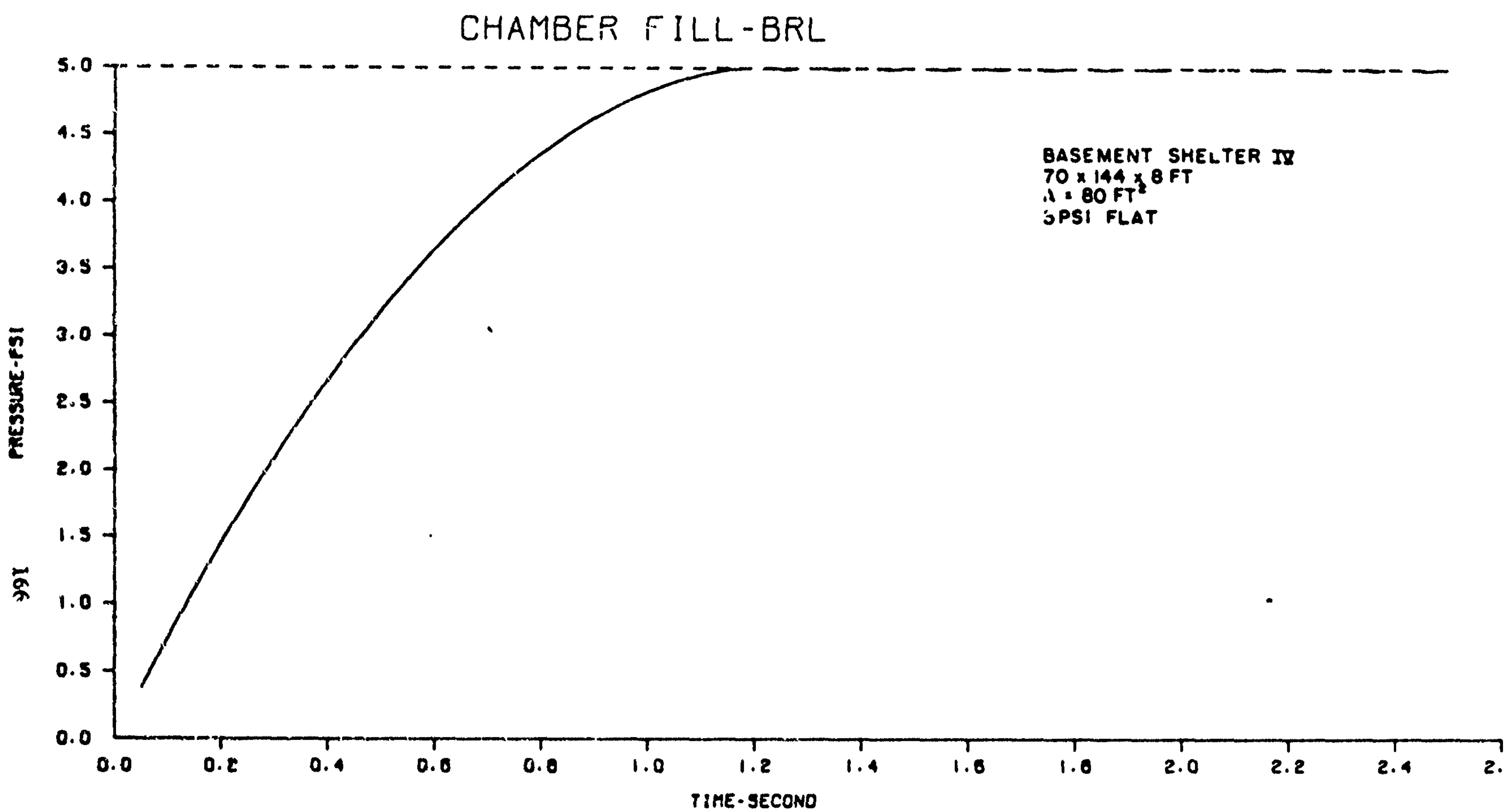

Figure F-4. Continued

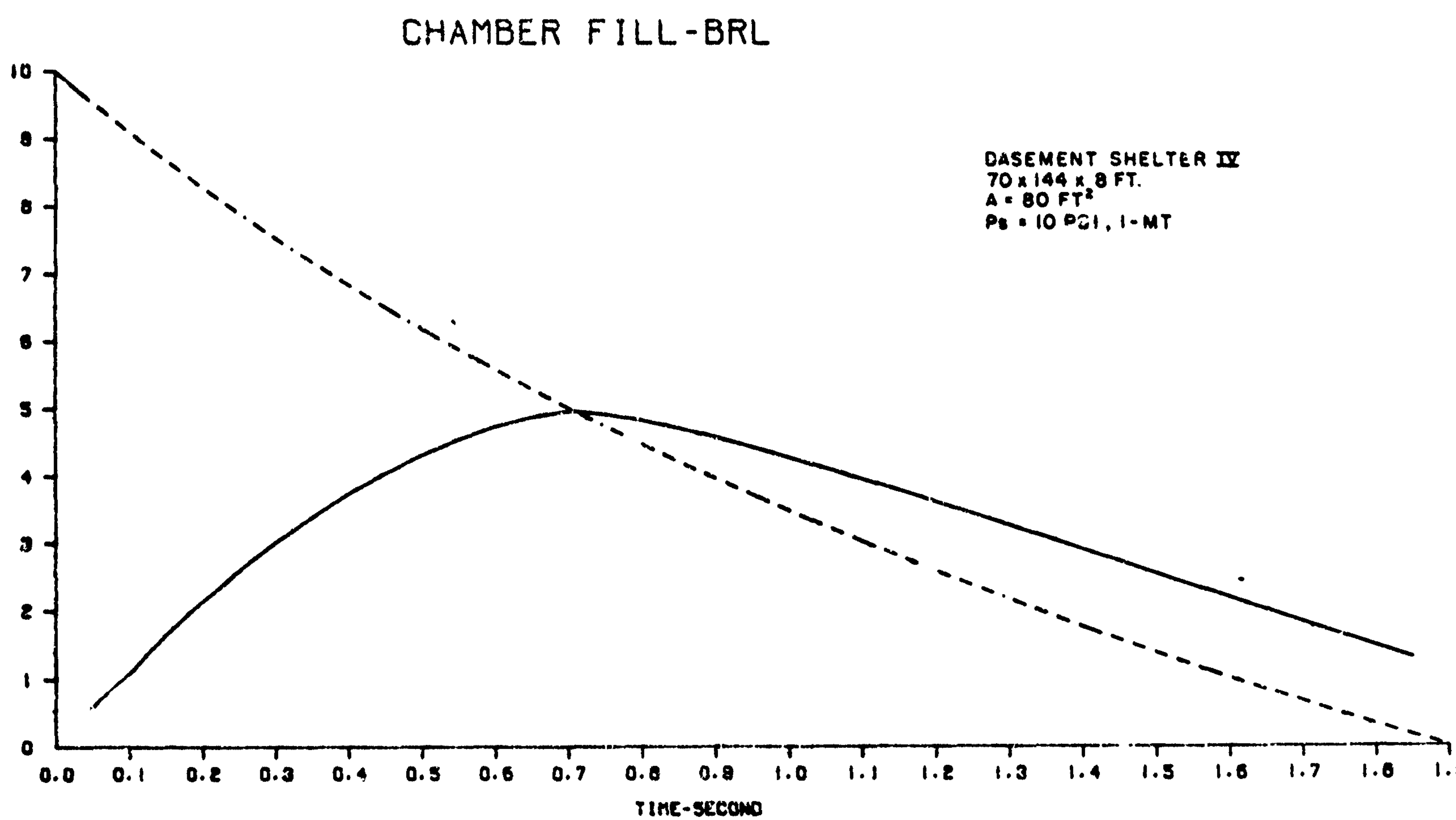

Figure F-4. Continued

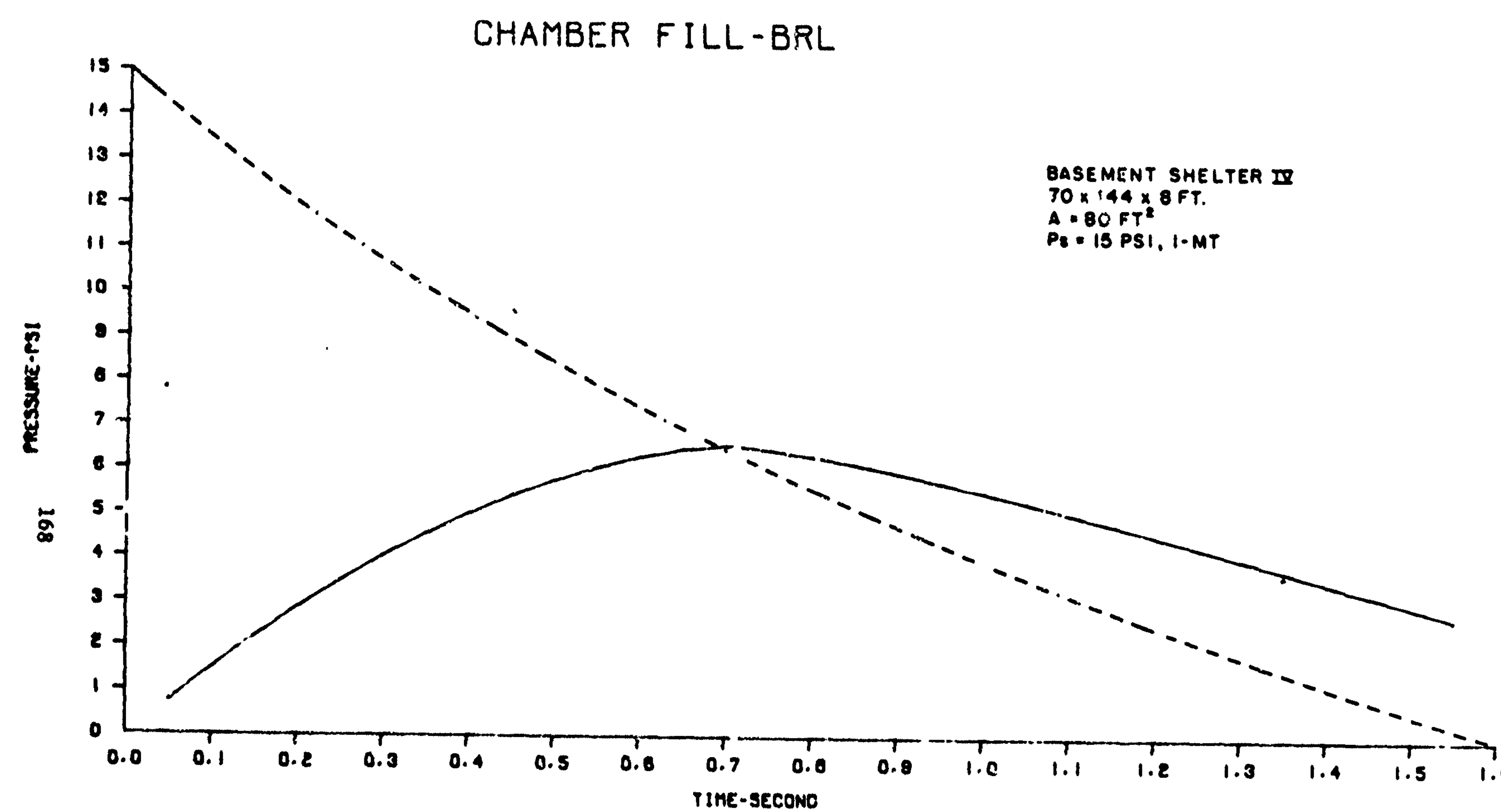

Figure F-4. Continued

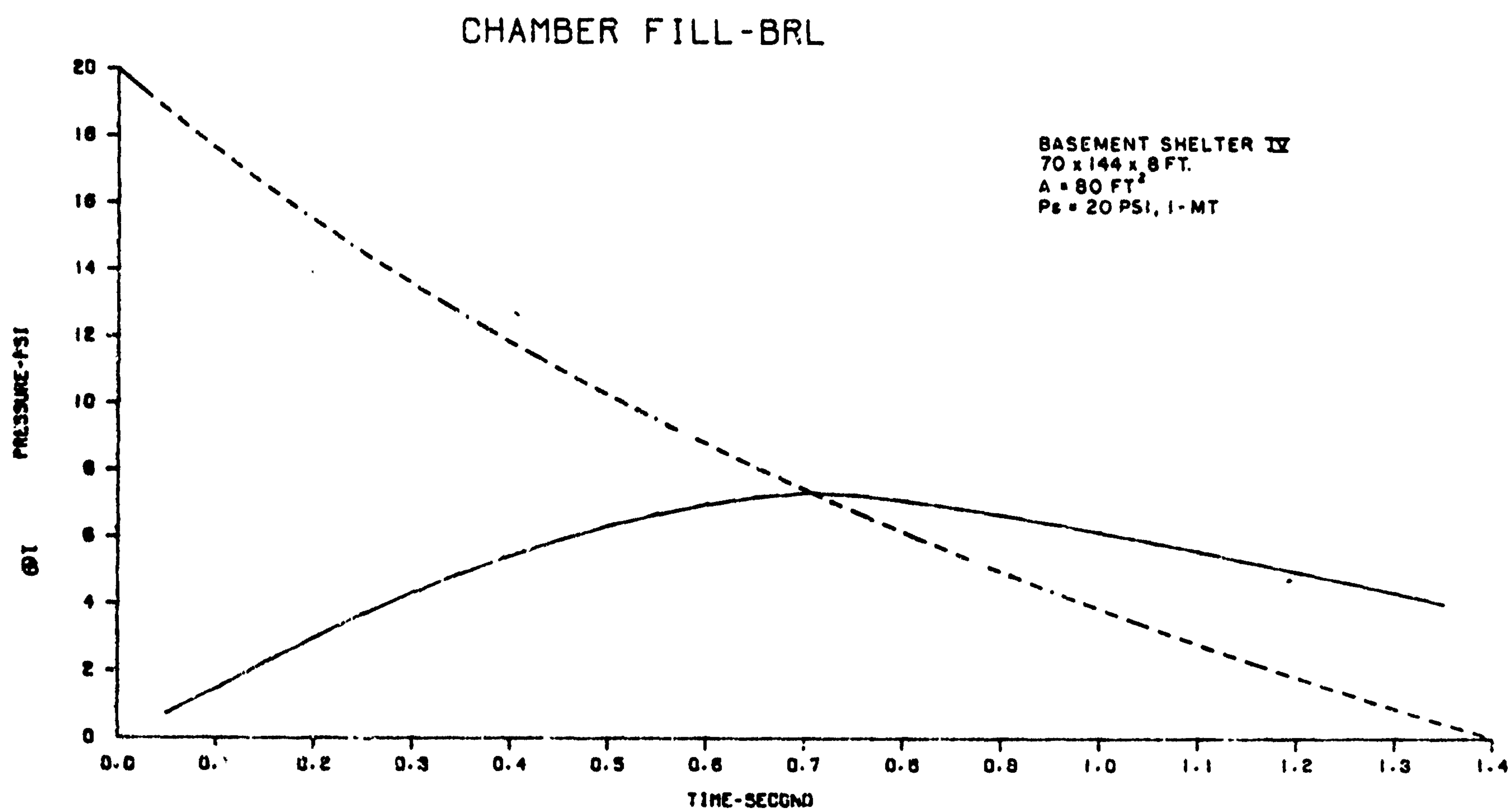

Figure F-4. Continued

APPENDIX F.

FILL PRESSURE AND MOTION PREDICTIONS FOR CYLINDERS IN BASEMENT SHELTERS

2. MOTION PREDICTIONS FOR CYLINDERS

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Table F-I Motion Parameters from Basement I
20x40x8 feet 3 psi, I-MT
150 lb. cylinder, 15 3/4 in. dia x 22 in. high

Time,sec	Distance,ft	Velocity, ft/sec	Acceleration, ft/sec^2
.01000	.00330	.00000	33.06889
.02000	.00940	.33068	27.93073
.03000	.01783	.60999	23.23446
.04000	.02815	.84234	18.97703
.05000	.03998	1.03211	15.15568
.06000	.05300	1.18366	11.76790
.07000	.06689	1.30134	8.81149
.08000	.08141	1.38946	6.28449
.09000	.09636	1.45230	4.18525
.10000	.11155	1.49415	2.51235
.11000	.12687	1.51928	1.26466
.12000	.14223	1.53192	.44131
.13000	.15760	1.53634	.04169

5 psi

.01000	.00585	.00000	58.58312
.02000	.01675	.58583	50.37350
.03000	.03192	1.08956	42.80134
.04000	.05069	1.51757	35.86077
.05000	.07240	1.87618	29.54644
.06000	.09651	2.17165	23.85345
.07000	.12248	2.41018	18.77739
.08000	.14990	2.59796	14.31434
.09000	.17835	2.74110	10.46081
.10000	.20753	2.84571	7.21381
.11000	.23717	2.91785	4.57075
.12000	.26706	2.96355	2.52954
.13000	.29705	2.98885	1.08851
.14000	.32707	2.99973	.24643
.15000	.35710	3.00220	.00253

10 psi

.01000	.01823	.00000	182.32147
.02000	.05223	1.82321	157.71715
.03000	.09977	3.40038	135.33088
.04000	.15881	4.75369	115.05038
.05000	.22753	5.90419	96.76901
.06000	.30429	6.87188	80.38531
.07000	.38762	7.67574	65.80247
.08000	.47625	8.33376	52.92788
.09000	.56905	8.86304	41.67275
.10000	.66505	9.27977	31.95169
.11000	.76341	9.59929	23.68235
.12000	.86345	9.83611	16.78513
.13000	.96460	10.00396	11.18285
.14000	1.06644	10.11579	6.80045
.15000	1.16864	10.18379	3.56475
.16000	1.27097	10.21944	1.40421
.17000	1.37333	10.23348	.24867
.18000	1.47569	10.23597	.02917

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Table F-I (continue ,

15 psi

Time,sec	Distance, ft	Velocity, ft/sec	Acceleration,ft/sec^2
.02000	.08608	3.00074	260.65863
.04000	.26244	7.85592	192.46389
.06000	.50441	11.41326	137.08822
.08000	.79215	13.92155	93.05949
.10000	1.11008	15.60098	59.05867
.12000	1.44639	16.64597	33.88793
.14000	1.79258	17.22751	16.44413
.16000	2.14305	17.49491	5.69661
.18000	2.49466	17.57714	.66863

20 psi

.02000	.11347	3.95514	343.72756
.04000	.34614	10.36081	254.52475
.06000	.66580	15.07087	182.42912
.08000	1.04665	18.41621	125.26097
.10000	1.46847	20.68548	81.10125
.12000	1.91589	22.13006	48.23316
.14000	2.37776	22.96779	25.09488
.16000	2.84650	23.38593	10.24088
.18000	3.31760	23.54327	2.31027
.20000	3.78903	23.57170	.00068

Table F-II Motion Parameters From Basement II

30x60x8 ft 3 psi, 1 MT

15 3/4 in. dia x 27 in. high

Time,sec	Distance, ft	Velocity, ft/sec	Acceleration, ft/sec^2
.02000	.01318	.00000	32.96207
.04000	.03748	.65924	27.78210
.06000	.07100	1.21488	23.06139
.08000	.11204	1.67611	18.79370
.10000	.15907	2.05198	14.97340
.12000	.21074	2.35145	11.59546
.14000	.26587	2.58336	8.65542
.16000	.32345	2.75647	6.14939
.18000	.38267	2.87945	4.07405
.20000	.44286	2.96094	2.42660
.22000	.50353	3.00947	1.20481
.24000	.56437	3.03356	.40696
.26000	.62522	3.04170	.03186

5 psi

Time,sec	Distance, ft	Velocity, ft/sec	Acceleration, ft/sec^2
.02000	.02333	.00000	58.33863
.04000	.06668	1.16677	50.02485
.06000	.12698	2.16726	42.38618
.08000	.20144	3.01499	35.41051
.10000	.28754	3.72320	29.08682
.12000	.38300	4.30494	23.40517
.14000	.48580	4.77304	18.35663
.16000	.59418	5.14017	13.93331
.18000	.70661	5.41884	10.12823
.20000	.82181	5.62140	6.93543
.22000	.93875	5.76011	4.34982
.24000	1.05664	5.84711	2.36727
.26000	1.17492	5.89445	.98452
.28000	1.29329	5.91414	.19921
.30000	1.41165	5.91813	.00986

Table F-II. Motion Parameters from Basement II (continued)

10 psi

Time,sec	Distance, ft	Velocity, ft/sec	Acceleration,ft/sec^2
.04000	.20785	3.63375	156.26570
.08000	.62995	9.42556	112.70200
.12000	1.20367	13.56455	77.82372
.16000	1.87938	16.38708	50.56671
.20000	2.61892	18.18852	30.01539
.24000	3.39423	19.22884	15.37043
.28000	4.18608	19.73702	5.92275
.32000	4.98306	19.91439	1.03242
.36000	5.78060	19.93725	.11112

15 psi

Time,sec	Distance, ft	Velocity, ft/sec	Acceleration,ft/sec^2
.04000	.34186	5.98326	256.33425
.08000	1.03421	15.47033	183.85524
.12000	1.97360	22.21770	126.69671
.16000	3.07921	26.81436	82.58583
.20000	4.28956	29.76247	49.62901
.24000	5.55971	31.49148	26.21704
.28000	6.85884	32.36876	10.95217
.32000	8.16817	32.70744	2.59120
.36000	9.47906	32.77210	.00043

20 psi

Time,sec	Distance, ft	Velocity, ft/sec	Acceleration,ft/sec^2
.04000	.44576	7.82215	332.18849
.08000	1.34205	20.06684	234.04322
.12000	2.55016	28.62006	158.26901
.16000	3.96403	34.33637	101.04585
.20000	5.50475	37.92530	59.27491
.24000	7.11603	39.97803	30.37620
.28000	8.76035	40.98660	12.13920
.32000	10.41569	41.35740	2.61057
.36000	12.07251	41.42062	.00830

Table F-III. Motion Parameters from Basement III

40 x 80 x 8 ft 3 psi 1-MT

156 lb cylinder 15 3/4 in. dia x 22 in. high

Time,sec	Distance,ft	Velocity, ft/sec	Acceleration,ft/sec^2
.05000	.07506	.00000	30.02556
.10000	.20699	1.50127	22.74741
.15000	.38024	2.63864	16.52744
.20000	.58183	3.46502	11.33339
.25000	.80126	4.03171	7.14029
.30000	1.03051	4.38873	3.92514
.35000	1.26394	4.58498	1.67174
.40000	1.49829	4.66857	.36797
.45000	1.73266	4.68697	.00618

5 psi

.05000	.13368	.00000	53.47493
.10000	.37155	2.67374	41.67223
.15000	.68804	4.75736	31.44991
.20000	1.06140	6.32985	22.74520
.25000	1.47352	7.46711	15.50506
.30000	1.90985	8.24237	9.68552
.35000	2.35931	8.72664	5.25114
.40000	2.81421	8.98920	2.17452
.45000	3.27019	9.09792	.43598
.50000	3.72624	9.11972	.02328

10 psi

.05000	.40307	.00000	161.23126
.10000	1.11013	8.06156	121.59332
.15000	2.03990	14.14122	89.08309
.20000	3.12666	18.59538	62.79678
.25000	4.31836	21.73522	41.97514
.30000	5.57500	23.83398	25.97286
.35000	6.86721	25.13262	14.23441
.40000	8.17512	25.84434	6.27488
.45000	9.48718	26.15808	1.66452
.50000	10.79929	26.24131	.01602

Table F-III. (continued)

15 psi

Time,sec	Distance,ft	Velocity, ft/sec	Acceleration, ft/sec^2
.05000	.66709	.00000	266.83608
.10000	1.83373	13.34180	199.82120
.15000	3.36488	23.33286	145.80351
.20000	5.15294	30.62304	102.76192
.25000	7.11365	35.76113	69.06240
.30000	9.18277	39.21425	43.36205
.35000	11.31323	41.38235	24.53778
.40000	13.47277	42.60924	11.63202
.45000	15.64184	43.19085	3.81099
.50000	17.81174	43.38139	.33182

20 psi

.05000	.87918	.00000	351.67256
.10000	2.41319	17.58362	261.93307
.15000	4.42373	30.68028	190.60335
.20000	6.77034	40.21074	134.43116
.25000	9.34405	46.93230	90.83629
.30000	12.06220	51.47412	57.77653
.35000	14.86429	54.36294	33.57909
.40000	17.70850	56.04190	16.84543
.45000	20.56865	56.88417	6.37587
.50000	23.43158	57.20297	1.11232
.55000	26.29474	57.25858	.09408

Table F-IV. Motion Parameters from Basement IV

70 x 144 x 8 ft. 3 psi 1-MT

156 lb. cylinder 15 3/4 in. dia. x 22 in. high

Time,sec	Distance,ft	Velocity,ft/sec	Acceleration,ft/sec^2
.05000	.08029	.00000	32.11617
.10000	.22624	1.60580	26.26460
.15000	.42480	2.91903	21.04616
.20000	.66447	3.97134	16.44067
.25000	.93522	4.79338	12.43046
.30000	1.22846	5.41490	9.00021
.35000	1.53705	5.86491	6.13687
.40000	1.85521	6.17175	3.82951
.45000	2.17655	6.36323	2.06928
.50000	2.50401	6.46669	.84928
.55000	2.82988	6.50916	.16456
.60000	3.15578	6.51739	.01202

5 psi

Time,sec	Distance,ft	Velocity,ft/sec	Acceleration,ft/sec^2
.05000	.13994	.00000	55.97806
.10000	.39673	2.79890	46.73701
.15000	.74958	5.13575	38.42488
.20000	1.17994	7.05699	31.00341
.25000	1.67139	8.60716	24.43891
.30000	2.20960	9.82911	18.70190
.35000	2.78223	10.76421	13.76683
.40000	3.37889	11.45255	9.61184
.45000	3.99109	11.93314	6.21856
.50000	4.61222	12.24407	3.57191
.55000	5.23751	12.42266	1.66001
.60000	5.86398	12.50566	.47400
.65000	6.49047	12.52936	.00801

10 psi

Time,sec	Distance,ft	Velocity,ft/sec	Acceleration,ft/sec^2
.05000	.40924	.00000	163.69790
.10000	1.15214	8.18489	133.46044
.15000	2.16354	14.85791	107.40438
.20000	3.38761	20.22813	85.06474
.25000	4.77679	24.48137	66 04462
.30000	6.29093	27.78360	50.00295
.35000	7.89678	30.28375	36.64470
.40000	9.56686	32.11598	25.71289
.45000	11.27940	33.40163	16.98193
.50000	13.01756	34.25073	10.25255
.55000	14.76910	34.76336	5.34662
.60000	16.52589	35.03069	2.10399
.65000	18.28364	35.13589	.37893
.70000	20.04147	35.15483	.03740

Table F-IV (Continued)

15 psi

Time,sec	Distance, ft	Velocity, ft/sec	Acceleration, ft/sec^2
.05000	.71836	.00000	287.34471
.10000	2.01133	14.36723	229.84568
.15000	3.75811	25.85951	181.51974
.20000	5.85753	34.93550	141.05701
.25000	8.22541	41.98835	107.38577
.30000	10.79234	47.35764	79.61996
.35000	13.50182	51.33864	57.01924
.40000	16.30870	54.18960	38.95817
.45000	19.17783	56.13751	24.90220
.50000	22.08293	57.[illegible]8262	14.38866
.55000	25.00556	58.10206	7.01158
.60000	27.93422	58.45263	2.40933
.65000	30.86351	58.57310	.25457
.70000	33.79342	58.58583	.24588

20 psi

Time,sec	Distance, ft	Velocity, ft/sec	Acceleration, ft/sec^2
.05000	.93853	.00000	375.41574
.10000	2.61590	18.77078	295.52859
.15000	4.86762	33.54721	229.74490
.20000	7.55864	45.03446	175.71769
.25000	10.57862	53.82034	131.58824
.30000	13.83827	60.39975	95.86368
.35000	17.26624	65.19294	67.32779
.40000	20.80664	68.55933	44.97497
.45000	24.41695	70.80808	27.96054
.50000	28.06616	72.20610	15.56276
.55000	31.73325	72.98424	7.15328
.60000	35.40579	73.34191	2.17390
.65000	39.07861	73.45060	.11801
.70000	42.75272	73.45650	.51551